International review of environmental assessment tools and databases

Report 2001-006-B-02

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Sustainable Built Assets

Project 2001-006-B
Environmental Assessment Systems for Commercial Buildings

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September 2002

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PREFACE

The Cooperative Research Centre for Construction Innovation (CRC CI) is a national research, development and implementation centre focused on the needs of the property, design, construction and facility management sectors. Established in 2001 and headquartered at Queensland University of Technology as an unincorporated joint venture under the Australian Government's Cooperative Research Program, the CRC CI is developing key technologies, tools and management systems to improve the effectiveness of the construction industry. The CRC CI is a seven year project funded by a Commonwealth grant and industry, research and other government support. More than 150 researchers and an alliance of 19 leading partner organisations are involved in and support the activities of the CRC CI.

There are three research areas:

- Program A - *Business and Industry Development*
- Program B - *Sustainable Built Assets*
- Program C - *Delivery and Management of Built Assets*

Underpinning these research programs is an *Information Communication Technology* (ICT) Platform.

Each project involves at least two industry partners and two research partners to ensure collaboration and industry focus is optimised throughout the research and implementation phases. The complementary blend of industry partners ensures a real-life environment whereby research can be easily tested and results quickly disseminated.

The major project in the **Sustainable Built Assets** core area is an Automated Environmental Assessment System for Commercial Buildings incorporating a CAD-based tool and associated material-performance databases. These are being combined to facilitate real-time environmental appraisal of commercial building design from concept stage to detailed specification to meet a growing need from designers and regulators for real-time appraisal of design performance of constructed assets.

In the current marketplace for the design and construction industry it is impossible for organisations to spend significant resources examining the environmental impacts of different products and evaluating the performance of different components and systems. This project will enable industry to make these types of assessments by providing a uniform level of information, and tools to access the information on environmental measures for different products and designs in real time.

This Working Paper (Report 2001-006-B-02) is part of a series of Working Papers and Progress Reports for the core area of **Sustainable Built Assets**.

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EXECUTIVE SUMMARY

Objective

Existing widely known environmental assessment models, primarily those for Life Cycle Assessment of manufactured products and buildings, were reviewed to grasp their characteristics, since the past several years have seen a significant increase in interest and research activity in the development of building environmental assessment methods. Each method or tool was assessed under the headings of description, data requirement, end-use, assessment criteria (scale of assessment and scoring/ weighting system) and present status

Findings

Fourteen models (including three Australian models) used world wide in relation to environmental assessment of buildings, were compared on the basis of their criteria covered. All models were compared with each other according to the selected comparison criteria: assessment level, criteria covered and weighting. A brief description for each model is given and the databases necessary to be able to operate some of the models/tools are also listed.

The models generally address assessment at the building level, based on some form of Life Cycle Assessment database except for BEES and Eco-quantum, which are focused on building products. Most models excluded economic aspects except for BEES and LCAid while most models emphasize environmental loadings such as global warming, indoor air quality as well as energy and resource consumptions.

The comparison results show that there no complete model satisfied all criteria considered here. Even though the Green Building Challenge scores as a better model of the considered models, it has limitations because it is a framework and not a simulation model and users are expected to use other tools to simulate energy performance, estimate embodied energy and emissions, predict thermal comfort and air quality, etc.

Some tools, such as LEED, BREEAM and NABERS include broad criteria with simple checklists, which include site selection, water efficiency, building reuse, or indoor environmental quality control and energy using information which is easily accessible. The others a re more quantitatively focussed and less subjective.

For the weighting method for each model compared here, most models give all criteria equal weight partially due to the difficulty of assigning weight to criteria (LEED) or fixed weight which cannot reflect relative importance between criteria due to regional differences or conditions (BRREAM, Ecoprofile). GBC and BEES employ a flexible weighting method, which can include a weight by each user appropriate to their regions or conditions.

All existing models reviewed contribute to environmental assessment of building during the life cycle with different degrees of success. However, several remarks can be made which can lead to improving the effectiveness of these models:

- A more comprehensive assessment model, extended to include building or community level, is needed to overcome problems due to limited focus.
- The ability to readily check different alternative criteria at the same time is most important in practice but many models do not have the ability of quick, in-depth and extensive assessment for comparison of alternatives, although alternatives can be assessed in turn.
- Requiring a special educated assessor can be limitation.
- Time-consuming effort to input large quantities of data specifically acquired for the assessment restricts wide spread use of some models. A new user-oriented model is needed to provide a more convenient tool which is easily accessible.
- Most models use data which cannot be applied directly to Australia.

- Most models do not use a transparent weighting system in their assessment criteria where equal or fixed weighting which may lead to misconstrued interpretations.

Next steps

A major step in resolving some of the difficulties identified above would be to develop a material analysis decision-support system which interfaces to Industry Foundation Classes (IFC) complaint CAD software for environmental and cost assessments of commercial building designs. The outline of the steps in such a process for calculating an environmental impact assessment are:

1. Obtain the plans of the building
2. Create a 3D CAD object model of the building.
3. Extract the drawing data into an industry standard file describing all the objects in the drawing as an Industry Foundation Classes (IFC) file.
4. Calculate the environmental emissions, resource usage, and energy in creating the materials in the building from the IFC database, the databases of environmental impact of materials and the generic default reasoning rules relating the materials to objects.
5. Display the results such as performance indicators, impact breakdowns, etc for the users to analyse.

The chosen approach (designated LCADesign) to fast and practical estimates of environmental impacts directly from 3D CAD drawings at the design stage requires 3D CAD objects, accurate quantity functions, generic materials formulas and extensive environmental impact databases.

INTRODUCTION

The past several years have seen a significant increase in interest and research activity in the development of building environmental assessment methods. Existing assessment models, which are used widely in the world, are reviewed to grasp their characteristics. Of the existing models, some models such as ASEM (A Simplified Energy Analysis Method) and DOE, which are narrowly focused on the energy performance or HQE (High Environmental Quality) and BASIX (Building Sustainability Index) that are proposed frameworks not yet completed, are not considered in the review because of their narrow focus. The methods and tools reviewed are primarily those for Life Cycle Assessment.

Each method or tool is assessed under the headings of:

- Description
- Data requirement
- End-use
- Assessment criteria
  - Scale of assessment
  - Scoring/ weighting system
- Present status

ENVIRONMENTAL ASSESSMENT OF BUILDINGS – RATINGS SYSTEMS

GBC (Green Building Challenge, GBTool)

Description

The Green Building Challenge (GBC) is a consortium of over twenty countries that is developing and testing a new method of assessing the environmental performance of buildings. The assessment framework has been produced in the form of software (GBTool) that facilitates a full description of the building and its performance, and also allows users to carry out the assessments relative to regional benchmarks. GBTool can handle both new building and renovation projects. The GBTool has been implemented on a Microsoft Excel spreadsheet and can be downloaded for evaluation and education purposes (Larsson and Cole, 2001).

Participating national teams test the assessment system on case study buildings in each country. The GBC has consists of two stages. An initial two-year process, including 14 countries, culminated in the GBC '98 conference in Vancouver in October 1998, where 34 projects were evaluated in depth. Work resulting from a second two-year round of development was displayed and reviewed at the international Sustainable Building (SB) 2000 conference in Maastrict, the Netherlands, in October 2000, which is a continuation of the GBC '98 process and an 18-month period of review, modification and testing of the GBC Assessment Framework and GBTool (Cole and Larsson, 2000).

The three general goals for the Green Building Challenge process are to:

- Advance the state-of-the-art in building environmental performance assessment methodologies,
- Maintain a watching brief on sustainability issues to ascertain their relevance to "green" building in general, and to the content and structuring of building environmental assessment methods in particular, and
- Sponsor conferences that promote exchange between the building environmental research community and building practitioners and showcase the performance assessments of environmentally progressive buildings.

These goals reflect the acknowledged success of the GBC process in having significantly increased the understanding of building environmental assessment through international collaboration. In addition to the above general goals, two specific objectives of GBC 2000 process are to:

- Develop an internationally accepted generic framework that can be used to compare existing building environmental assessment methods and used by others to produce regionally based industry systems, and
- Expand the scope of the GBC Assessment Framework from green building to include environmental sustainability issues and to facilitate international comparisons of the environmental performance of buildings.

The first goal above is particularly important. It accepts that the primary emphasis of the Green Building Challenge effort primarily lies in the development of a comprehensive, generic assessment framework and not necessarily in the development of a commercially viable version of GBTool. The GBC process can thus constitute a forum for discussion and possible convergence of existing methods. Irrespective of this emphasis, many of the member countries are, of course, interested in the eventual commercial implementation of the GBC assessment framework and GBTool, or some variant of it (Larsson and Cole, 2001).

Data requirement

The required data is in two forms:

Quantitative: detailed statistical values of the predicted consumption of energy, water, land use, materials, environmental emissions as well as the measurable aspects of indoor environmental conditions.

Qualitative: most aspects of indoor environment, health issues, design issues related to longevity, design and building operations planning and management provisions, and environmental loading on immediate surroundings, mainly in terms of the effects on neighbouring or adjacent properties.

End-use

The end use is as a building design and assessment tool.

Assessment criteria

The assessment criteria for GBC (GBC, 2000) are presented in Table 1.

The first four criteria (Resource Consumption, Environmental loadings, Indoor environmental quality and Service quality) are considered core requirements in the GBC assessment. Criteria and sub-criteria in these performance issues are scored using the –2 to +5 assessment scale. The remaining criteria are important but are not scored in a GBC 2000 assessment. These characteristics of the case-study buildings are simply reported as text descriptions.

Table 1 Assessment criteria for GBC

Criteria	Sub-criteria	Note
Resources consumption	life cycle energy use, land use, net use of water, and net consumption of materials	Core requirement in GBC 2000 assessment
Environmental loadings	emission of greenhouse gases (1), emission of ozone-depleting substances (2), emission of gases leading to acidification (3), emission leading to formation of photo-oxidants (4), emissions with eutrophication potential (5), solid wastes (6), liquid effluent (7), hazardous wastes (8), and environmental impacts on site and adjacent properties (9)	Core requirement but not included (4), (5) and (8) in subcriteria at GBC 2000 assessment
Indoor environmental quality	air quality and ventilation, thermal comport, daylighting illumination and visual access, noise and acoustics, electro-magnetic pollution	Core requirement but electro-magnetic pollution was not included in GBC 2000 assessment.
Service quality	flexibility and adaptability (1), controllability of systems (2), maintenance of performance (3), privacy and access to sunlight and views (4), quality of amenities and site development (5), impact on quality of service of site and adjacent properties (6)	Core requirement but not included (4), (6) in GBC 2000 assessment.
Economics	life cycle cost, capital cost, operating and maintenance cost	Not be scored in GBC 2000 assessment
Pre-operation management	construction process planning, performance tuning, building operations planning	Not be scored in GBC 2000 assessment
Commuting transport	greenhouse gas emission, acidification gas emission, photo-oxidant formation gas emission	Not be scored in GBC 2000 assessment

Scale of assessment

The spatial boundary is the building level (for office building, school, and multi-unit residential building). Some criteria refer to the public transport system and other services of the surrounding community, such as waste minimization, which have implications for the city and district scales. However these are taken into account from the viewpoint of the individual building. In addition the whole methodology is based around reduction of impacts, which implies a longer-term (more than 20 years) interest in protecting and preserving the environmental systems.

Scoring/ weighting system

All performance criteria and sub-criteria assessed are scored (from -2 to +5), then summed using two types of weighting: default by GBC or modified weighting by each of the national teams also participated in the GBC. Performance scores are presented in a consistent manner all relative to an explicitly declared benchmark - the zero (0) on the performance scale. When scoring for criteria, the score is assigned according to the rule that is shown in Table 2.

Intermediate scores (1, 2, and 4) represent varying degrees of performance between the primary benchmarks (i.e., score 1 represent a moderate improvement over the industry benchmark performance, e.g., “good practice” within the region).

The overall score is calculated, via individual scores and weights. There are two types of results shown: Environmental Sustainability Indicators (ESI), which are absolute numbers; and bar charts that show weighted scores (-2 to +5) relative to the benchmarks (0).

Table 2 Scoring criteria for GBC

Scoring	Description
-2* and –1	levels of performance below the acceptable level in the region that building is located, for occupancies specified
0	the minimum level of acceptable performance in the region that building is located for occupancies specified
3	best practise
5	the best technically achievable, without consideration of cost

*This is assigned when performance is clearly inferior to accepted industry norms.

In defining appropriate benchmarks, quantifiable issues (energy use, water use etc.) are assumed to be either minimum code requirements or typical practice, depending on access to reliable data. In either case there must be a clear description and rationale of the choice.

For many of the qualitative criteria considerable judgement will be required. The default benchmarks for these are simply a declaration of what would be considered to be a typical condition or typical practice for the building type in the region.

Present status

GBC has been tested on a total of 34 buildings in 14 different countries. The results of these assessments were reported at the Green Building Challenge ‘98 Conference held in Vancouver, Canada and reviewed in SB 2000 conference in Maastrict, the Netherlands, in October 2000. The current round of the GBC process will culminate in the presentation of the assessed buildings at the SB 2002 conference held in Oslo, Norway in September 2002. Another major opportunity for each country to display the state-of-the-art of its industry will be presented in SB 2002.

BREEAM (Building Research Establishment Environmental Assessment Method)

Description

The Building Research Establishment (BRE) in the UK developed the Building Research Establishment Environmental Assessment Method (BREEAM), which was found to be the most widely recognized international method. It was implemented in 1990, and provides authoritative guidance on ways of minimizing the adverse effects of buildings on the local and global environments (Curwell and Spencer, 1999). The assessment is based on 'credits' awarded for a set of performance criteria. When a building has been evaluated using BREEAM, the result is a single score, which enables owners or occupants to gain recognition for their building's environmental performance.

Environmental performance is assessed under nine main categories: 1) Management (of the building and the occupant organization), 2) Health and Comfort, 3) Energy, 4) Transport, 5) Water Consumption, 6) Materials, 7) Land Use, 8) Site Ecology, and 9) Pollution. Assessment credits are awarded for the environmental performance in range of criteria in each of these categories leading to a category score. Finally an environmental weighting system is applied across the nine category scores in order to determine the final BREEAM rating. The weighting system applied is the result of a consultation process across a wide range of professionals and other stakeholders in the UK, and is updated from time to time.

The system is modularized to facilitate assessment of new and refurbished buildings, existing and occupied buildings. The core module provides for the assessment of the buildings potential environmental performance and allows cross comparison between existing buildings and between new designs and existing buildings. The design and procurement module is for the assessment of new build and refurbishment at the design stage and covers additional issue over the core module relevant to design such as land use and selection of materials and components. The management and operation module is for assessment of buildings that are in use and adds additional issues such as the health and well-being of users. Specialist assessors licensed by BRE undertake assessments.

Data requirement

The required data is in two forms:

Quantitative: energy and water consumption, materials data, environmental profiling system based on LCA data (used to determine the credits attributed for materials)

Qualitative: the use of high frequency ballasts in fluorescent lighting, (a health and comfort factor) or whether efforts have been made to plant new trees (a site ecology factor).

End-use

The end use is a building design and environmental assessment tool.

Assessment criteria

The criteria in BREEAM are shown in Table 3.

Scale of Assessment

Buildings (office, home, superstore, and industrial unit) and their operation form the primary focus of assessment. Estate issues are addressed though consideration of the environmental implications of location, transport to the building and its site ecology.

Scoring/ Weighting System

For each of the criteria set out, the building is assessed against performance criteria set by BRE and awarded credits based on the level of performance against each criterion. The percentage of credits achieved under each category is then calculated and environmental weightings are applied to produce an overall score for the building. The overall score then translated into a BREEAM rating of "Pass", "Good", "Very good", or "Excellent". The weighting system is predetermined through the national consultative process and so users cannot apply their own individual weighting priorities.

Table 3 Assessment criteria in BREEAM

Criteria	Description
Management	Overall policy, commissioning and procedural issues
Energy use	Operational energy and CO_2 issues
Health and well being	Indoor and external issues affecting health and well being (lighting, air quality, hazardous materials, radon, indoor noise, hot water system)
Pollution	Air (CO_2, NO_x, CFCx, HCFCs, Halons) and water pollution
Transport	Transport related CO_2 and location related factors
Land use	Greenfield and brownfield sites
Ecology	Ecological value of the site
Materials	Environmental implication of building materials
Water	Consumption and water efficiency

Present status

It is first implemented in 1990 and subsequently revised and extended in scope. Currently BRE estimates that 20-30% of new office accommodation constructed since 1990 has received a rating using the method in the UK and adapted for and marketed in other jurisdictions. Presently, more than 500 buildings have been certified by BREEAM. The latest version of BREEAM have been launched in 1998 (EcoHomes, the version of BREEAM for homes in 2000), and BREEAM versions have been developed for Canada, Hong Kong, New Zealand, and BREEAM derivative scheme in Norway (Grace, 2000).

Green Globes

Description

Green Globes is an online building and management audit tool that helps property owners and managers measure the environmental performance of their buildings against best practices in areas such as energy, water, hazardous materials, waste management and indoor environment. This was developed under the auspices of the Canadian Energy Efficiency Alliance (CEEA) and CMHC, and launched in January of 2002 with sponsorship by Enbridge Consumer Gas, the Ontario Ministry of Environment (MoE), CMHC, and Ontario Power Generation (OPG). Using a confidential questionnaire, it generates an online report (CEC 2002, Green Globes 2002).

Green Globes is the newest addition to the BREEAM/Green Leaf suite of environmental assessment tools for buildings.

The program's core premise is that environmental leadership and responsibility make business sense. BREEAM/Green Leaf tools are used in hundreds of North American buildings and are currently applied by:

- Public Works and Government Services Canada (PWGSC) for all federally owned buildings.
- The Department of National Defense for the design of new buildings.
- The Federation of Canadian Municipalities for the Municipal Building Retrofit Program.
- The Hotel Association of Canada.
- The City of Toronto Better Building Partnership.
- Major property management firms.

Data Requirement

The required data is in two forms:

Quantitative: energy and CO2 emissions, water consumption, noise level, NOx emissions,

Qualitative: energy features/management, water efficiency, lighting level, refrigerant type

End-use

The end use is a building Design and environmental assessment tool.

Assessment Criteria

Audit criteria are based on the internationally accepted Building Research Establishment Environmental Assessment Method. (BREEAM) and BREEAM Canada, published by the Canadian Standards Association (CSA). The assessment criteria in Green Globes are shown in Table 4.

Scale of Assessment

Buildings (office, home, superstore, and industrial unit) and their operation form the primary focus of assessment. Estate issues are addressed though consideration of the environmental implications of location, transport to the building and its site ecology.

Scoring/ Weighting System

The program provides two kinds of ratings:

Scores: it give the percentage of possible points that have been awarded for implementing best practices as identified in the internationally recognized criteria of BREEAM and BREEAM Canada published by the Canadian Standards Association (CSA). Scores are given for each module and for each subsection.

Quintile ratings: it shows performance relative to other buildings that have been assessed. These are provided only for buildings that have undergone third party verification. The user can benchmark their building against buildings of similar age, type or geographical zone.

Weightings: The UK BREEAM weightings are based on a series of consultations, which Building Research Establishment (BRE) conducted with 1,000 participants who were asked to assign environmental, social, and economic values to each of the building-related activities and their environmental impacts. In Canada, the BREEAM/Green Leaf/Green Globes tools use the mean of the British BREEAM, the Harvard and the EPA environmental weightings. The overall results are consistent with those of other assessment tools.

Table 4 Assessment criteria in Green Globes

Criteria (Performance)	Sub-criteria	Points
Energy	Energy consumption	80
	Energy features	130
	Energy management	80
	Transportation	60
Water	Water efficiency	80
Resources	Waste reduction and recycling	45
	Site	65
Indoor environment	Indoor air	143
	Lighting	32
	Noise	10
Emissions	Air emissions	30
	Ozone depletion	45
	Water effluents	20
	Hazardous materials	47
	Hazardous Products, Health & Safety and WHMIS	33
Environmental management	EMS documentation	30
	Purchasing policy	25
	Emergency response	20
	Tenant awareness	25

Present status

Green Globes is an online building and management audit and maintained by the Canadian Energy Efficiency Alliance (CEEA).

LEED (Leadership in Energy and Environmental Design)

Description

The LEED (Leadership in Energy and Environmental Design) Green Building Rating System™ is a priority program of the US Green Building Council (US GBC, 2002). It is a voluntary, consensus-based, market-driven building rating system based on existing proven technology. It evaluates environmental performance from a "whole building" perspective over a building's life cycle, providing a definitive standard for what constitutes a green building.

LEED™ is based on accepted energy and environmental principles and strikes a balance between known effective practices and emerging concepts. Unlike other rating systems currently in existence, the development of LEED Green Building Rating System™ was instigated by the US Green Council Membership, representing all segments of the building industry, and has been open to public scrutiny (US GBC, 2002).

LEED™ is a self-assessing system designed for rating new and existing commercial, institutional, and high-rise residential buildings. It is a feature-oriented system where credits are earned for satisfying each criterion. Different levels of green building certification are awarded based on the total credits earned (see Table 5). The system is designed to be comprehensive in scope, yet simple in operation.

LEED™ rating system uses a simplified checklist format that facilitates its use in the design process – design teams often use the checklist as the basis for a charrette and discussions of which strategies and credits they will try to achieve in the building.

LEED™ awards ratings of certified, silver, gold, and platinum. To obtain a rating, a building must meet seven prerequisites and then obtain points for credits related to sustainable sites, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality.

Table 5 Assessment criteria in LEED rating system

Criteria	Sub-criteria	Points*
Sustainable Sites	site selection, urban redevelopment, brownfield redevelopment, alternative transportation, reduced site disturbance, stormwater management, landscape & exterior design to reduce heat Islands, light pollution reduction	14
Water Efficiency	water efficient landscaping, innovative wastewater technologies, water use reduction	5
Energy & Atmosphere	optimise energy performance, renewable energy, additional commissioning, ozone depletion, measurement & verification, green power	17
Materials & Resources	building reuse, construction waste management, resource reuse, recycled content, local/regional materials, rapidly renewable materials, certified wood	13
Indoor Environmental Quality	carbon dioxide (CO_2) monitoring increase ventilation effectiveness, construction IAQ management plan, low-emitting materials, indoor chemical & pollutant source control, controllability of systems, thermal comfort, daylight & views	15
Innovation & Design Process	innovation in design, LEED™ accredited professional	5

*Building is certified as Silver, Gold and Platinum according to the obtained points (26-32 points Silver 33-38 points Gold 39-51 points Platinum 52-69 points)

Data requirement

Required data is detailed statistical values of the predicted consumption of energy, water, materials, as well as measurable aspects of indoor environmental conditions and site.

End-use

The end use is a building design tool.

Assessment criteria

All of criteria and sub-criteria in LEED rating system are described in Table 5. Based on the criteria/sub-criteria, points are assigned. Then, a building is certified as "Silver", "Gold" or "Platinum" according to the obtained points (26-32 points - Silver 33-38 points - Gold 39-51 points - Platinum 52-69 points).

Scale of assessment

Spatial boundary is building level.

Scoring/weighting system

Each criterion is specified as credits and user selects criteria for scoring. Then, rates based on total number of points scored by user. All criteria are weighted equally, except for number of points assigned.

Unlike other rating systems, the development of LEED Green Building Rating System™ was instigated by the US Green Council Membership, representing all segments of the building industry and has been open to public scrutiny.

Different levels of green building certification are awarded based on the total credits earned. In evaluating a building using the LEED criteria, for example, there are minimum, mandatory requirements in areas such as building commissioning, energy efficiency, indoor air quality, ozone depletion/CFCs, smoking ban, comfort, and water (Table 6). A full list of credits is in Appendix A - LEED credit checklist. Once the mandatory requirements are met, a building can earn 'credits' in 14 areas. Depending on the total credits, a building receives a rating level of 'Silver', 'Gold', or 'Platinum'.

Table 6 Seven prerequisites to obtain a rating in LEED green building rating system

Criteria	Prerequisite	Objective
Sustainable Sites	Erosion and Sedimentation Control	to control erosion to reduce negative impacts on water and air quality
Energy and Atmosphere	Fundamental Building Systems Commissioning	to verify and ensure that fundamental building elements and systems are designed, installed and calibrated to operate as intended
	Minimum Energy Performance	to establish the minimum level of energy efficiency for the base building and systems
	CFC Reduction in HVAC&R Equipment	to reduce ozone depletion
Materials and Resources	Storage and Collection of Recyclables	to facilitate the reduction of waste generated by building occupants that is hauled to and disposed of in landfills
Indoor Environmental Quality	Minimum IAQ Performance	to establish minimum indoor air quality (IAQ) performance to prevent the development of indoor air quality problems in buildings, maintaining the health and well being of the occupants
	Environmental Tobacco Smoke (ETS) Control	to prevent exposure of building occupants and systems to environmental tobacco smoke

Present status

After development of the LEED green building rating system by US GBC, 14 buildings were certified using LEED 1.0, and 9 buildings were certified using the LEED 2.0 rating system. More than 470 buildings are registered to be certified using LEED green building rating system by 2002.

Presently, the LEED 2.1 rating system is available, and the LEED 3.0 rating system is scheduled for release in 2005 following balloting by USGBC members and pilot testing of the new criteria.

NABERS (National Australian Building Environmental Rating System)

Description

The NABERS (National Australian Building Environmental Rating System) project commenced in April 2001, is being designed to assess many types of new and existing buildings –particularly commercial and residential – and to enable the building owner or operator to undertake the rating annually with or without the need to hire independent assessors. This model is a voluntary system and its uptake is expected to grow as building users come to understand the importance of minimizing environmental impacts and discover the accompanying financial savings, improved comfort and health benefits. This model addresses the impact associated with both the construction of a building and its use (Robert Vale et al., 2001).

NABERS is based on a series of questions that can be answered by the building owner or user without the need for specialist assessors. The content of NABERS project is comprised of the following part:

- Evaluate previous and existing Australian systems for environmental rating of buildings.
- Evaluate current world-wide systems for environmental rating of buildings, and analyze their strengths and weaknesses.
- Evaluate existing Australian building energy rating systems.
- Formulate Australian Building Environmental Rating System.
- Strategy for implementation of the system.
- Identification of, and consultation with, stakeholders.

There are two types of questions in the NABERS system; Building questions (which apply to the physical fabric of the building) and User questions (which apply to how people make use of the building). This is intended to attempt to make a division in the rating system between things that are more-or-less fixed by the construction of the building, and things over which the users have some control.

Data Requirement

The required data is in two forms:

Quantitative: site (building, plant, and paved) area, building cost, building age, renovation time, energy use, greenhouse gas emissions, water consumption, indoor air quality, transport distance to local shop (supermarket/bank/post office, and urban center)

Qualitative: site, structural (floors, walls and roofs) type, information related to waste treatment and collection

End-use

The end use is a building design and environmental assessment tool.

Assessment Criteria

The NABERS Commercial and Domestic Ratings are each comprised of eight headings, and a number of subheadings – currently 30 for NABERS Commercial and 28 for NABERS Domestic. This means that for each rating there is a theoretical maximum score, of 150 stars for NABERS Commercial, and 140 stars for NABERS Domestic. The headings in NABERS are shown in Table 7 (The subheadings are listed in Appendix D - NABERS rating headings and subheadings).

Table 7 Headings and its score in NABERS

Headings	Rating	
	Commercial*	**Domestic****
Land	Total 25 stars for recent buildings and 20 stars for building over three years old	Total 25 stars
Materials	Total 10 stars for recent buildings, 15 stars for building more than 3 years old	Total 20 stars
Energy	Total 25 stars	Total 25 stars
Water	Total 10 stars	Total 10 stars
Interior	Total 5 stars	Total 10 stars
Resources	Total 15 stars	Total 10 stars
Transport	Total 25 stars	Total 30 stars
Waste	Total 15 stars	Total 20 stars

* This includes offices, shops, libraries, schools, hospitals, theaters, industrial premises, warehouses, hotels, motels, museums, restaurants, and opera houses.

** This includes houses, flats, apartments, units, co-housing, etc.

Scale of Assessment

The assessment is focused on buildings and their operation.

Scoring/ Weighting System

The overall score for each heading is derived from the average of the rating scores of the subheadings. The overall scores are expressed as stars: the better the environmental performance, the higher the number of stars. Depending on the total stars earned, a building receives a rating level of ‘Green’, ‘Bronze’, ‘Silver’, ‘Gold’, ‘Platinum’. If no stars or only half a star are earned in any category, the total score is described as a “NABERS Basic” score. However, if a building earns scores of at least one star in each category, it will qualify for “NABERS Medals” as set out in Table 8.

Table 8 Scoring system of NABERS

NABERS basic/medals	Description
NABERS Basic	The addition of all the stars earned in each subheading produces the “NABERS Basic” score.
NABERS Green	A building which earns at least one star in each main heading will earn both its overall score, and the title “NABERS Green”.
NABERS Bronze	A building which earns at least two stars in each main heading will earn both its overall score, and the title “NABERS Bronze”.
NABERS Silver	A building which earns at least three stars in each main heading will earn both its overall score and the title “NABERS Silver”.
NABERS Gold	A building which earns at least four stars in each main heading will earn both its overall score and the title “NABERS Gold”.
NABERS Platinum	A building which earns at least five stars in four main headings will earn both its overall score and the title “NABERS Platinum”.

Present status

NABERS is under being developed after commencing in April 2001. The draft model is being refined following feedback from the workshops that Environmental Australia hosted in 2001 and the final model should be complete by mid-2003.

CASBEE (Comprehensive Assessment System for Building Environmental Efficiency)

Description

CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) has been launched to establish a new system for environmental sustainable building in Japan. CASBEE comprises a variety of assessment tools: Pre-design assessment tool, DfE tool, Eco-labeling tool, and sustainable operation and renovation tool. CASBEE project, designated to be carried out over three years, is currently underway, and involves in collaboration of the academic, industrial and governmental sectors.

Data Requirement

The required data are detailed statistics values on the predicted consumption of energy, water, land use, materials, and environmental emissions as well as the measurable aspects of indoor environmental conditions.

End-use

The end use is environmental assessment tool for building materials and design.

Assessment Criteria

Criteria Based on the restructure of assessment items, “Q: Building Environmental Quality & Performance” is broken down into three categories; “Q-1 Indoor Environment”, “Q-2 Quality of Service”, and “Q-3 Outdoor Environment on Site”. “LR: Reduction of Building Environmental Loadings” is also sub-grouped into “LR-1 Energy”, “LR-2 Resources & Materials”, and “LR-3 Off-site Environment”. LR represents not the “L: Building environmental loadings” itself, but the level of performance in minimizing building environmental loadings imposed outside the hypothetical boundary.

The assessment criteria in CASBEE are shown in Table 9.

Scale of Assessment

The assessment is focused on buildings and their operation.

Scoring/ Weighting System

The assessment results for each assessment item are given as scores on the Score Sheet as S_Q, S_{LR}. The score sheet is divided into sections representing the assessment categories. Scores are given based on the scoring criteria for each assessment item. These criteria applied to assessments are determined in consideration of the level of technical and social standards at the time of assessment. A five-level scoring system is used, and a score of level “3” indicates an “average”. Each assessment item, such as Q-1, Q-2 and Q-3 is weighted so that all the weighting coefficients within the assessment category Q sum up to 1.0. The scores for each assessment item are multiplied by the weighting coefficient, and aggregated into total scores for Q or LR, as S_Q, S_{LR} respectively.

Present status

CASBEE is three- year project and is currently underway.

Table 9 Assessment criteria in CASBEE

Criteria		Re-criteria	Sub criteria
Building environmental quality and performance	Indoor environment	Noise & acoustics	Noise, Sound insulation, Sound absorption
		Thermal comfort	Room temperature control, Moisture control, Type of air conditioning system
		Lighting & illumination	Daylighting, Anti-glare measures, Illumination levels, Lighting control ability
		Air quality	Sources control, Ventilation, Operation plan
	Quality of service	Service ability	Functionality and workability, Mentality: coziness
		Durability	Earthquake-resistance, Daily maintenance/updating and
		Feasibility & adaptability	Space margin, Floor load margin, Adaptability of facilities
	Outdoor environment on site	Maintenance and creation of ecosystem	-
		Town scape and landscape	-
		Local characteristics and culture	-
Reduction of building environmental loadings	Energy	Building thermal load	Building orientation, Thermal load of windows, Insulation level of exterior wall and roof
		Natural energy utilization	Direct utilization of natural energy, Indirect utilization of natural energy
		Efficiency in building system	HVAC system, Ventilation system, Lighting system, Water heating system, Elevator system
		Efficient operation	Monitoring, Operational management system
	Resources and materials	Water resource	Water saving, utilization of rainwater and gray water
		Eco-materials	Use of recycled materials, use of wood and natural materials, use of hazardous materials, reuse of existing skeleton, etc., waste disposal, avoidance of CFCs and Halons
	Off-site environment	Air pollution	Emission of air pollutants, emission of water pollutants, emission of soil pollutants
		Noise and offensive odours	Noise generation, offensive odours
		Wind damage	-
		Lighting damage	-
		Heat island effect	-
		Load on local infrastructure	Lead on sewage treatment systems, lead on traffic management systems, lead on waste management system

ENVIRONMENTAL ASSESSMENT OF BUILDINGS – LIFE CYCLE ASSESSMENT SYSTEMS

ENVEST (Environmental impact estimating design software)

Description

ENVEST (Environmental impact estimating design software) is the first UK software tool that estimates the life cycle environmental impacts of a building from the early design stage. ENVEST presently considers the environmental impacts of materials used during construction and maintenance, and energy and resources consumed over the building's life.

Using minimal data entered, ENVEST allows designers to quickly identify those aspects of the building which have the greatest influence on the overall impact. All impacts are assessed using Ecopoints – a measure of total environmental performance – which allow the designer to compare different designs and specifications directly (BRE, 2002).

Data Requirement

The required data is in two forms:

Quantitative: length, width, plan depth, number of storeys, storey height, gross area, glazing area, operational life, ground floor, upper floor area, external (internal) walls area, roofs area, window area, lighting load, water consumption

Qualitative: building type, location, soil type, heating (boiler and heating system), light switch control, ventilation type, cooling system, lift type and capacity

End-use

The end use is a building design and environmental assessment tool.

Assessment Criteria

The assessment criteria in ENVEST are shown in Table 10.

Table 10 Assessment criteria in ENVEST

Criteria	Sub-criteria
Resource	Fossil fuel depletion/extraction, minerals extraction, water extraction
Environmental loadings	Climate change, acid deposition, ozone depletion, human toxicity, low level ozone depletion, ecotoxicity, eutrophication, waste disposal

Scale of Assessment

Assessment of initial design for office buildings.

Scoring/ Weighting System

ENVEST measures the environmental impacts using the UK Ecopoints score, which is a single score assessment of environmental impact. Ecopoints provide a weighted score for impacts in the criteria shown in Table 10. UK Ecopoints are derived by adding together the score for each issue, calculated by multiplying the normalized impact with its percentage weighting. To aggregate the environmental impacts into a single value, BRE used expert panels from across the industry's stakeholder groups to judge the importance of many sustainability issues, covering environmental, social and economic issues. The resulting relative weighting between environmental issues measured by BRE have been used to weight the normalized environmental impacts to provide the Ecopoints score (BRE, 1999).

100 Ecopoints are equal to the impact of 1 UK citizen for 1 year. Alternatively, 1 Ecopoint can be described as equal to any of the following:

- 320 kWh electricity
- 83 m^3 water: enough to fill 1,000 baths
- 65 miles by articulated truck
- landfilling 1.3 tonnes of waste
- Manufacturing ¾ tones brick (250 bricks)
- 540 tonne kms by sea freight
- 1.38 tonnes mineral extraction

ENVEST provides the facility for measuring impacts per square metre of building gross floor area.

Present status

Presently BRE is developing ENVEST 2 version, which will be web-based, for estimating for estimating whole life cycle costs as well as environmental impacts.

ATHENA

Description

Athena is a LCA-based environmental decision support tool for building materials and buildings which was developed by Athena Sustainability Institute in 2000. Athena helps designers achieve the best environmental footprint by showing side-by-side tabular and graphical comparisons of as many as five separate conceptual designs. It is a practical, easy-to-use decision support tool that provides high quality environmental data and assists with the complex evaluations required to make informed environmental choices. With Athena all the basic LCA work is done out of the sight and mind of the user.

Data Requirement

The required data is general description (location, gross floor area, building life, building type), selection of typical assemblies or specific quantities of individual products.

End-use

The end use is a environmental assessment tool for building materials and design.

Assessment Criteria

The assessment criteria in Athena are shown in Table 11.

Table 11 Assessment criteria in Athena

	Criteria (Performance)
Energy or resource	Embodied primary energy use
Environmental impact	Global warming potential
	Solid waste emissions
	Pollutants to air
	Pollutants to water
	Natural resource use

Scale of Assessment

Building materials and building's life cycle (industrial, institutional, office, and both multi-unit and single family residential buildings) including material manufacturing, related transportation, construction, maintenance, repair and replacement as well as demolition and disposal for the building.

Scoring/ Weighting System

After specifying a design by selecting from typical assemblies or by entering specific quantities of individual products, Athena breaks down the selected assemblies into their respective products for the purpose of applying the LCI databases. Then the results show the absolute inventory results or the six aggregated summary impact measures (e.g., energy consumption, air pollution index, water pollution index, global warming potential, resource usage, solid waste emissions) as a graphical or tabular format.

Present status

The first commercial version of Athena Environmental Impact Estimator, Athena 2.0, was released in June, 2002.

ECO-QUANTUM

Description

Eco-Quantum is simulation-based tool intended to enable a designer to quickly identify environmental consequences of material choices and water and energy consumption of their designs (Mak et al. 1997; Kortman et al., 1998). This tool calculates the environmental effects during the entire life cycle of the building from the moment the raw materials are extracted, via production, building and use, to the final demolition or reuse. This includes the impact of energy, the maintenance during the use phase and the differences in the durability of parts of the construction related to the life span of the building.

Two kinds of versions of Eco-Quantum are available (Eco-Quantum Research and Eco-Quantum Domestic). Both are provided with information from a stand-alone version of the Dutch LCA program SimaPro 4 (Pre Consultants 1997). Eco-Quantum Research is a tool for analyzing and developing innovative and complex designs for sustainable buildings and offices and Eco-Quantum Domestic is a tool which architects can apply to quickly reveal environmental consequences of material and energy use of their designs of domestic buildings.

Data requirement

The required data is energy and water consumption, materials data, environmental profiling system based on LCA data (used to determine the credits attributed for materials).

End-use

The end use is a building and building material design.

Assessment criteria

The assessment criteria in Eco-Quantum are shown in Table 12.

Table 12 Assessment criteria for ECO-QUANTUM

Criteria	Items
Natural resource	Consumptions of energy, water, material
Environmental loading	Air emission, water emission, and waste
Land use	-
Biodiversity	-

Scale of assessment

Primarily the assessment is focus on buildings and their operation. Also, building materials and components are included in the assessment.

Scoring/weighting system

Eco-Quantum relates the environmental profiles to the corresponding material and energy flows. By doing so the environmental interventions related to the total life cycle of the building are accumulated in the form of raw materials, energy, land-use (input), waste and emissions (output). And then, the environmental interventions are converted on the basis of characterisation factors of the LCA methodology (Heijungs et al., 1992) into the various environmental effect scores such as exhaustion of resources, ecotoxicity and greenhouse effect. In the following step these environmental effect scores are automatically converted into four environmental indicators: depletion of resources, emissions, energy consumption and waste according to the Dutch Environmental Rating methodology.

Present status

It is extensively tested by architects, building industry, municipalities and other organizations. Various case studies have been undertaken using Eco-Quantum:

- A new test with version 3.0 in 10 municipalities: around 50 residential projects (1999);
- A new test with version 3.0 in 12 branches of the building product industry (1999);
- Calculation of two design for one office building in Amsterdam (1998);
- A research project in which various levels of the Energy Performance Standards with related equipment are calculated;
- Research projects with steel, concrete and wood frame industry.

ECOPROFILE

Description

Ecoprofile, which is a method for simple environmental assessment of buildings, is a top down method for environmental assessment of existing office buildings. It includes three principal components that are given the designations “External Environment”, “Resources” and “Indoor Climate” (Pettersen, 2000). Each of the principal components has 4-6 sub-areas with a total of approximately 90 parameters assessed within these areas. Each sub-area is weighted. The method is based on the use of standardized schemes, questionnaires and reports to minimize the work of assessment and this makes it easy and cheap to use. The method has been under development since 1995, but has been operative since autumn 1998.

Data requirement

Quantitative and qualitative data is used (not included economics, such as LCC). As a quantitative data are needed such as energy consumption and water consumption, and materials inputted. The method does not go into details concerning impact categories like global warming potential, ozone layer depletion, etc.

End-use

The end use is a building design and assessment tool.

Assessment criteria

The assessment criteria in Ecoprofile (Pettersen, 2000) are shown in Table 13. The sub-components are listed in Appendix C - Ecoprofile sub-components.

Table 13 Assessment criteria in Ecoprofile and their weighting value

Principal components	Sub-components	Weight
External environment	Release to air	3
	Release to ground	3
	Release to water	3
	Waste management, toxic substances	2
	Outside areas	1
	Transport	2
Resources	Energy	10
	Water	1
	Materials	-
	Land	-
Indoor climate	Thermal climate	3
	Atmospheric climate	2
	Acoustic climate	1
	Aclinic climate	1
	Mechanical climate	1
	Cross factors	3

Scale of assessment

Buildings and their operation form the primary focus of assessment.

Scoring/weighting system

Each criterion is scored and sub-criterion is weighted from 1 to 3 (except for energy as 10). Then, the results which are added scores for criteria are presented as bar charts for the major categories or target plot for detail within the major categories (resource depletion, environmental emission, energy consumption, and waste).

Present status

At present the method covers only existing office buildings, but work is going on to adapt the method for dwellings. Approximately 50 existing office buildings had been assessed by 1999 (Pettersen, 1999).

BEAT (Building Environment Assessment Tool)

Description

Building Environment Assessment Tool (BEAT), developed at the Danish Building and Urban Research, is an LCA-based inventory tool and database for the environmental assessment of building products, building elements and buildings based on the Danish life cycle assessment method EDIP (Environmental Design of Industrial Products) ($BY_{OG}BYG$, 2002). BEAT is a relation database designed using Microsoft Access and consists of a database with environmental data and a user interface with an integrated inventory and assessment tool.

The database is used for storing data (which the user is free to add to, edit or delete) on environmental parameters for unit processes like:

- Extraction of 1 unit 'raw material' (e.g. 1 tonne of sand or 1 m^3 of clay).
- Manufacture of 1 unit 'building product' (e.g. 1 tonne of cement, 1 m^2 of gypsum board or 1 brick).
- Construction of 1 unit 'building element' (e.g. 1 m of foundation, 1 m^2 of 'exterior wall' or 1 window).
- Construction, operation, maintenance and demolition of 1 unit 'building'.
- Production of 1 unit 'energy from a given fuel' (e.g. 1 MJ of natural gas).
- Transportation of 1 unit 1 product 1 km by a given means of transportation (e.g. 1 tkm by truck).

Based on these data, the inventory tool can calculate the total environmental impacts, such as total energy consumption (and it's distribution on energy sources), raw material consumption (including fuels), and emissions (to air, water and soil) connected with:

- Production of a building product.
- Construction, maintenance and demolition of a building element.
- Construction, operation, maintenance and demolition of a building.

The database currently contains data for most conventional primary building products used n the Danish building industry (cement, concrete, gypsum boards etc.) as well as a large number of commonly used building elements. In addition to these it also contains a number of energy sources and means of transport. It calculates the environmental impacts caused by the construction materials, considering the materials' entire life cycle in an LCA-approach, and the expected energy consumption in the building's operation phase.

Data Requirement

The required data are building type and quantity of the building elements (e.g. m2 of exterior wall, meter of foundation type, number of windows type, etc) or quantity of the building products (e.g. m3 of concrete type, m2 of gypsum plate type, etc).

End-use

The end use is an environmental assessment tool for building products and building elements/buildings.

Assessment Criteria

The assessment criteria are not hard-coded in BEAT, user may define it. But by default BEAT use the Danish EDIP method, which includes assessment criteria shown in Table 14.

Table 14 Assessment criteria in BEAT 2000

	Criteria (Performance)
Energy or resource	Fuel resources consumption
	Metal-resources consumption
	Minerals
Environmental impact	Global warming
	Ozone depletion
	Acidification
	Nutrient enrichment
	Ecotoxicity
	Human toxicity
	Persistent toxicity
	Photochemical ozone formation
	Hazardous waste
	Slag & ash
	Volume waste
	Radio active waste

Scale of Assessment

Building materials and buildings' life cycle including production, construction, use, operation and demolition as well as waste management of construction wastes.

Scoring/ Weighting System

After defined a product, a building element or a building in the database, the inventory tool can perform a calculation of the total environmental impact related to its manufacture, operation, maintenance and demolition. The inventory tool multiplies the consumption of raw materials and energy and emissions to air, water and soil for every product with the amounts consumed of the product and subsequently sums them. This gives the total consumption of raw materials and energy respectively, and emissions related to the production of the above products. Energy consumption and emissions related to transportation of products and raw materials are summed. Finally all energy consumptions are converted to fuel consumption and emission. This finishes the calculation. The calculated data can be shown as input/output tables, environmental effect tables, normalized environmental profile and normalized and weighted environmental profiles using the Danish EDIP method (Environmental Design of Industrial Products).

Present status

Presently BEAT 2001 for Microsoft Access 97 is used, the current version is being used by many parties in the building sector, including a number of Danish building materials manufactures, architects and consulting engineers, municipalities and technical schools/universities in Denmark, Sweden and Norway. A new and significantly improved version of BEAT (BEAT 2002) will release within the end of 2002.

GreenCalc

Description

GreenCalc, developed by NIBE (Dutch Institute for Building Biology and Ecology) Consulting, is a computer tool which can be used to calculate the environmental load of an office building; it has been developed by order of the Dutch Government Buildings Agency (GBA). This model can be used for the calculation of the environmental load of new developments as well as of renovation projects.

To assess the environmental load of new developments, GreenCalc can be applied in various phases of the designing process. Both the consequential environmental damage caused by the building materials throughout their life cycle, and the environmental load of the building throughout its lifetime, as a result of fuel and drinking water consumption, are expressed in terms of money as so-called submerged environmental costs (cost per m^2 for the total life cycle of the building).

Four environmental aspects have been incorporated in the GreenCalc:

- Use of materials from construction to, and including, demolition - in the "materials" module;
- Energy consumption in the user phase (partly standardized) - in the "energy" module;
- Water consumption in the user phase - in the "water" module;
- Accessibility home-work traffic (car and public transport) - in the "mobility" module.

The computation modules in the GreenCalc are based on:

- NIBE's TWIN-model for the materials module;
- The NEN 2916 standard, `Energy performance of factories and offices' for the energy module;
- Bureau Opmaat en Boom's `WaterprestatieNormering' (water performance standards developed to the orders of the Utrecht local authority) for the water module;
- Bouwinfo Koster's accessibility module for the mobility module.

A file created within GreenCalc contains one project, which includes various building designs, each incorporating varying scenarios. Each scenario includes one material, one energy, one water, and one mobility module. Variations within the modules are expressed in different scenarios.

In the GreenCalc calculation, the module material is subdivided into raw materials, pollution, waste, environmental nuisance, ecological effect, energy, re-usability, repairability and life span. GreenCalc gives a view of the environmental cost over the different structural parts of the building and determines the total CO_2-production as a result of the material usage. The module energy consists of different parameters: building use, heating -, cooling-, ventilation- and hot water system, type of artificial lighting, use of solar energy, etc. These parameters are on itself the base for the Energy performance Ratio (EPC), which is an energy efficiency calculation based on the energy consumption within the building. The water module of GreenCalc calculates the effects on water usage. Parameters are the type of sanitary, use of fresh water or the substitution of fresh water by a "grey water" circuit (use of cleaned waste water for toilet flush, garden, etc.). Mobility looks at the location of the building in relation to its environment, infrastructure, connections and distances to public transportation.

Calculations made with Greencalc v.2.0 give a total score on a scale from 1 - 2000. The average building built in 1990 has a score of 100 and the goal for 2050 is buildings with a score of 2000.

Data Requirement

The required data contain general description of building (such as gross floor surface, ground floor area, roof surface, Surface sewerage pipes/rainwater catchment, Number of floors, Number of employees, Elevation surface, window percentage, window surface), materials information (building product, quantity, dimensions, environmental costs, total costs), energy-related information (use of building: business hours, occupation, and internal heat load, air-conditioning: heating, cooling, and ventilation, hot tap water: tap water and humidification, lighting and appliances and systems: appliances, systems, and elevators.

End-use

The end use is an environmental assessment tool for building and building materials design.

Assessment Criteria

The assessment criteria in GreenCalc are shown in Table 15.

Table 15 Assessment criteria in GreenCalc

Criteria (Performance)	Sub-criteria
Materials	Raw materials, pollution, waste, environmental nuisance, ecological effect, energy, re-usability, repairability
Energy	-
Water usage	Sanitary, use of fresh water etc.
Mobility	-

Scale of Assessment

Primarily the assessment is focus on office building of new developments as well as of renovation to calculate the environmental load.

Scoring/ Weighting System

In the model, the environmental assessment is translated into costs per m^2 for the total lifecycle of the building (construction, exploitation and demolition). GreenCalc calculates the environmental costs for the materials according to the TWIN-model (TWIN-model is consisted of two parts: a quantitative part and a qualitative part. This last part consists of two matrices, one for an environmental assessment and one for a health assessment. Due to the fact that these pairs are to be considered as twins, the whole is called the TWIN-model), which simplifies the criteria by weighting focus on human health (Haas, 1997).

Calculations made with Greencalc v.2.0 give a total score on a scale from 1 - 2000. The average building built in 1990 has a score of 100 and the goal for 2050 is buildings with a score of 2000.

Present status

Presently GreenCalc is released version 2.0. The model is used by engineering consultants.

BEES (Building for Environmental and Economic Sustainability)

Description

Building for environmental and economic sustainability (BEES) is an interactive computer design aid that helps users select building products for use in commercial office and housing projects in a way that balances environmental and economic criteria. A range of material options can be compared for different elements of the building, using graphical outputs of a range of environmental and economic criteria, considered individually or in combination (Lippiatt, 1999; 2000).

At present the tool contains 65 building products. Future versions of BEES are planned that will cover building components, or collections of elements (Lippiatt and Rushing, 2002).

BEES measures the environmental performance of building products by using the environmental life-cycle assessment approach. Economic performance is measured using the ASTM (American Society for Testing and Materials) standard life-cycle cost method, which covers the costs of initial investment, replacement, operation, maintenance and repair, and disposal. Environmental and economic performances are combined into an overall performance measure using the ASTM standard for Multi-Attribute Decision Analysis. For the entire BEES analysis, building products are defined and classified according to the ASTM standard classification for building elements.

Data requirement

The required data is in two forms:

Quantitative data, based on US building technology, is included in the system tool and so is not required of users. The environmental performance measure is derived using the LCA approach and covers six impacts (resource depletion, global warming, acidification, eutrophication, indoor air quality and solid waste).

Qualitative data required of users involves setting or adjusting the weightings between parameters, such as the balance between environmental issues and cost

Economic performance is derived using the ASTM standard LCC approach (ASTM, 1994) and includes the cost of purchase, installation, operation, maintenance, repair, replacement, and disposal over a 50-year use stage. Environmental and economic performances are combined using the ASTM standard for multi-attribute decision analysis.

End-use

The end use is a primarily building materials chosen in design.

Assessment criteria

The assessment criteria in BEES (Lippiatt, 2000) are shown in Table 16.

Scale of assessment

Components and Materials form the subject of assessment.

Scoring/weighting system

Environmental and economic values obtained are transformed by relative value. For environmental performance, BEES uses the LCA approach, following guidance in the ISO 14040 standard for LCA. For economic performance, it is measured using the American Society for Testing and Materials (ASTM) standard life cycle cost approach. Both performances are aggregated into a single score using the weighting factors (EPA Science Advisory Board study (1990), Harvard University Study (Norberg-Bohrn, 1992), or Equal weightings). The weighting systems are described in more detail in Appendix B - BEES weighting systems.

The user may set relative importance weights for 1) synthesizing environmental impact scores into an environmental performance score, 2) discounting future costs to their equivalent present value, and 3) combining environmental and economic performance scores into an overall performance score. Default values provided for all of this windows-based input.

Table 16 Assessment criteria for BEES

Criteria (Performance)		Items considered in BEES
Environmental criteria	Global warming	CO_2, CH_4, NOx
	Acid rain	SOx, NOx, NH_3, HF, HCl
	Eutrofication	P, NOx, NH_3, nitrogenous matter, nitrates, phosphorous, COD
	Resource depletion	Oil (in ground), natural gas (in ground), coal (in ground), bauxite (ore), Cd (ore), Cu (ore), Au (ore), Fe (ore), Pb (ore), Mn (ore), Hg (ore), Ni (ore), phosphate rock (in ground), Ag (ore), Sn (ore), U (ore), Zn (ore)
	Indoor air quality	VOC from floor coverings, interior wall finishes, wall and roof sheathing, wall and ceiling insulation
	Solid waste	
	Smog	NOx, VOC
	Ozone depletion	Methyl bromide, carbon tetrachloride, CFC11, CFC113, CFC114, CFC115, CFC12, Halon 1201, Halon 1202, Halon 1211, Halon 1301, Halon 2311, Halon 2401, Halon 2402, HCFC 123, HCFC124, HCFC141b, HCFC142b, HCFC22, HCFC225ca, HCFC225cb, methyl chloroform HC 140a
	Ecological toxicity	Hydrocarbons, NOx, CO, dioxines, HCl
	Human toxicity	NH_3, benzene, formaldehyde, Pb, phenolics
Economic criteria*	First cost	-
	Future cost	-

*economic performance is measured over a 50 year period

Present status

It has been used for a number of projects in the USA. 570 copies distributed at November 1999.

LCAid (Life Cycle Assessment tool)

Description

LCAid is a computer software developed by the NSW Department of Public Works and Services (DPWS). LCAid takes Life Cycle Assessment (LCA) information, which until now has been limited to LCA specialists, and makes it more accessible to other practitioners (e.g. architects, engineers, and portfolio managers) to make more complete environmental assessments. It is aimed at the building designer, and is a user friendly decision making tool using LCA methodology to evaluate the environmental performance of design options and to identify the largest impacts over the entire life cycle of a building (Eldridge, 2002).

Data Requirement

The required data is in two forms:

Quantitative: operational energy, waste, building material quantities

Qualitative: areas of project type, climate zone, operational, waste management, water management and water use as project and operational input

End-use

The end use is a building design and environmental assessment tool.

Assessment Criteria

The assessment criteria in LCAid are shown in Table 17.

Table 17 Assessment criteria in LCAid

Criteria (Performance)		Items considered in LCAid
Resource	Energy consumption	Energy
	Water consumption	Water
Environmental Loading	Greenhouse effect	CO_2, CFCs, HCFCs, HFCs, Halons, methane, N_2O, other chlorinated hydrocarbons
	Ozone depletion	CFCs, HCFCs, HFCs, Halons, other chlorinated hydrocarbons
	Heavy metals	Cadmium, mercury, lead, arsenic, copper, nickel, manganese, chrome
	Nutriphication	Ammonia/ammonium, nitrates, NOx, phosphates, COD
	Acidification	Ammonia, HCl, HF, NO, NO_2, NOx, SO_2, Sox
	Carcinogenesis	Aromatic hydrocarbons, and derivatives
	Summer smog	Chlorinated hydrocarbons., alcohols, aldehydes, saturated & unsaturared hydrocarbons, mercaptans, aromatic hydrocarbons, volatile organic compounds, ketones, phenols
	Winter smog	Dust, SO_2
Economics		Life cycle cost

Scale of Assessment

Buildings (office, home, superstore, and industrial unit) and their operation form the primary focus of assessment.

Scoring/ Weighting System

Given known quantities of components that make up a building, LCAid calculates the environmental impacts of the building over its whole life. Building materials quantities can be entered in LCAid by manually entering quantities and assigning materials from the LCAid library or importing quantities generated by a 3-D architectural drawing and assigning materials to each building element (3-D model is not essential). Life Cycle Inventories (LCI) of building materials are stored in a library in LCAid and are based on the DPWS LCI database. LCAid can read Boustead Model files and has a template for data to be entered for other LCA packages such as SimaPro.

Based on the entered data, environmental impacts are calculated using Eco Indicator 95 with the additional reporting of water consumption and solid waste produced.

Present status

LCAid is currently the subject of an Expression of Interest for further development.

COMPARISON OF THE MODELS

All models described above are compared with each other according to the selected comparison criteria: assessment level, criteria covered and weighting. A brief description for each model is summarized in Table 18. The databases necessary to be able to operate some of the models/tools are listed in Appendix E - Environmental assessment databases.

Assessment level

Building assessment level can be divided in three levels: assessment of building product, building, and community as shown in Figure 1. Presently, many of models address the building product and/or building assessment level based on some form of LCA database.

Most of models considered here are mainly focused on the assessment of "building level" except for BEES and Eco-quantum, which are focused on the "building products".

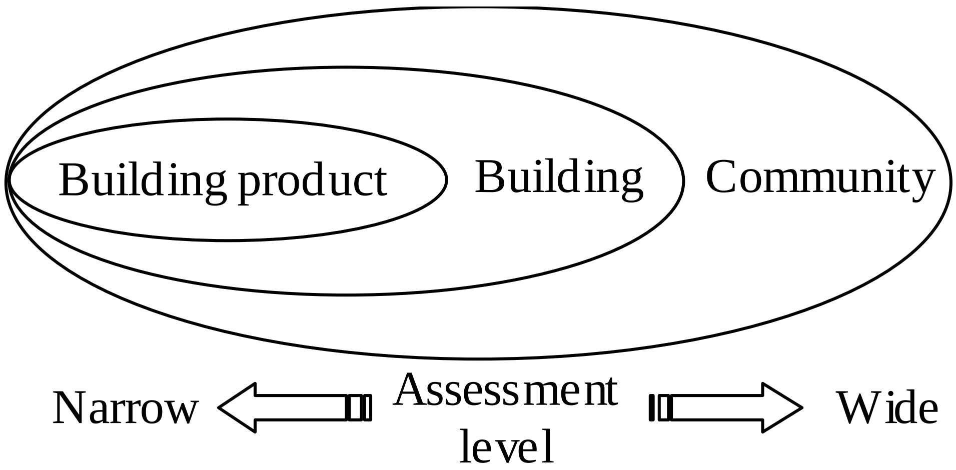

Figure 1 Building Assessment Level

Table 18 Scope of Assessment Models

Model	GBC	LEED	BREEAM	BEES	ECO-QUANTUM	Ecoprofile	LCAid
Nation	Canada	U.S.A	U.K	U.S.A	Netherlands	Norway	Australia
Main Developer	National Resource Canada (NRC) in 1995	US Green Building Council in 2000	Building Research Establishment in UK in 1990	National Institute of Standards and Technology (NIST) in 1994	IVAM Environ.l Research & W/E consultants in 1999	Norwegian Building Research Institute (NBI) in 1999	NSW DPWS
Purpose	Research/contribute to the state-of-the-art of building performance assessment during design or after completion	Voluntary, market-based assessment	Voluntary, consensus-based, market-focused assessment	Consensus-based decision support tool	LCA for building product and design improvement	LCA for existing office building	LCA for environmental assessment and design improvement
End-use	Building	Building	Building	Building product	Building product	Building	Building
Stakeholder	Researcher, organization	Building project team member - architect, designer, owner, builder	Building owner, Operator	Designer, builder, Product manufacturer	Architect, Building researcher	Building owner, Contractor, Building user	building designer
Type Assessed	·Office building ·Multi-unit residential building ·School building	·Office building, ·Institutional building, ·High-rise residential building	·Office building ·Residential building	·Building products	·Building products	·Office building	·Office building, ·Residential building, ·School, and ·Hospital
Present status	GBC `98: tested on 34 buildings (14 different countries) GBC 2000: 40 buildings (16 countries) by national team from 20 countries+	20 certified and more than 437 registered projects	·Used for 30% of new office construction in the UK	Used for a number of projects in the USA. 570 copies distributed at 11/99.	·50 residential projects by 1999	·Assessed 50 existing office buildings by 1999	-
Regional Scope	Participated countries (member+)	U.S.A and Canada	U.K	U.S.A	Netherlands	Norway	Australia

\+ Members: Austria, Australia, Brazil, Canada, Chile, Finland, France, Germany, Hong Kong, Italy, Japan, Korea, Netherlands, Norway, Poland, South Africa, Spain, Sweden, U.S.A., Wales

Table 18 Scope of Assessment Models (continued)

Model	ENVEST	NABERS	Athena	BEAT 2000	GreenCalc	Green Globes	CASBEE
Nation	U.K	Australia	Canada	Denmark	Netherlands	Canada	Japan
Main Developer	Building Research Establishment	Environment Australia	Athena Sustainable Materials Institute	Danish Building and Urban Research (DBUR)	NIBE (Dutch Institute for Building Biology and Ecology)	ECD Energy and Environment Canada	JSBC (Japan Sustainable Building Consortium)
Purpose	LCA for building and design improvement at early design stage	To rate the environmental impact of buildings	To encourage selection of material mixes and other design options for less environmental impacts	To clarify the environmental impact from building and develop strategies for reduction of environmental impacts	To give an environmental information for office building for the Dutch market	To give an environmental information by online measurement of energy, indoor health and environmental performance against best practice standards	To meet both the political requirements and market needs for achieving a sustainable society through building life cycle
End-use	Building	Building	Building/product	Building/product	Building	Building	Building
Stakeholder	Designer	Architect, designer, building owner, builder	Architect, researcher, Engineer	Researcher, Builder, consultant, building product manufacturer	Consultant	Building owner, Building manager	Designer, planner, builder
Type Assessed	·Office building	·Commercial buildings ·Residential buildings	industrial, institutional, office, multi-unit and single family residential buildings	Office, school, residential building	Office building, Commercial building	Office, Multi-unit residential building	Office building, Schools, Multi-unit residential building
Present status	-	Under developing, will be completed in mid-2003.	First commercial version is released on June, 2002.	BEAT 2000 is now being tested in various projects	Version 2.0 is released and several engineering consultants are used.	-	Three-year project, Being under developing
Regional Scope	U.K	Australia	North America	Denmark	Netherlands	North America	Japan

Criteria covered

When assessing a building, it is necessary to consider a number of factors such as energy and raw materials consumption, environmental loadings, etc. The Sustainability Advisory Council in NSW, Australia suggests ten broad categories for the sustainability index of a building, such as “social, transport, water, alteration water, stormwater, energy, alteration energy, waste, indoor air quality, and materials” (SAC 2002). In relation to these, fourteen kinds of principal targets are suggested as an effort for the sustainable building in Europe (see Appendix F - for more detail, Bruno Mesureur 2002, Gerad Deroubaix 2002). These criteria are similar to the suggestion of Cole et al (2000), in which economic and social concerns as well as environmental aspects of sustainability should be considered as sustainable criteria in building assessment.

Criteria covered in each model are described in Table 19. All models reviewed in here include environmental loadings and resource consumption while none of them includes any social concerns. In addition, economics is only included in BEES and LCAid though GBC includes economics but not be scored in GBC 2000.

Table 20 shows the assessment level in each model considered.

Table 19 Criteria in each model considered

Criteria			GBC	BREEAM	Green Globes	LEED	NABERS	CASBEE	ENVEST	ATHENA	ECO-QUANTRM	Ecoprofile	BEAT	GreenCalc	BEES	LCAid
Resource consumption	Energy	Embodied	√	√	-	-	√	-	√	√	-	-	-	-	√	-
		Operation	√	√	√	√	√	√	√	√	√	√	√	√	-	√
	Land		√	√	-	√	√	-	-	-	√	√	-	-	-	-
	Water		√	√	√	√	√	√	√	√	√	√	-	√	√	√
	Materials		√	√	√	√	√	√	√	√	√	√	√	√	√	√
Environ-mental loading	Air		√	√	√	-	√	√	√	√	√	√	√	√	√	√
	Solid		√	√	√	√	√	√	√	√	√	√	√	-	√	√
	Water		√	√	√	-	-	√	√	√	√	√	√	-	√	√
	Others		√	-	√	-	√	√	√	-	√	√	√	-	√	√
Indoor Environmental quality	Air		√	√	√	√	√	√	-	-	√	√	-	-	√	-
	Thermal		√	√	√	√	-	√	-	-	-	√	-	√	-	-
	Visual		√	-	-	-	-	-	-	-	-	√	-	-	-	-
	Noise		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Econ-omics	Life Cycle		√*	-	-	-	-	-	-	-	-	-	-	-	√	√
	Operation		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Social concerns			-	-	-	-	-	-	-	-	-	-	-	-	-	-

* GBC includes economics (life cycle cost, capital cost, operating and maintenance cost) in the criteria, but it’s not scored to aggregate into a single value in evaluation in GBC 2000.

Table 20 Assessment level of each model

model	GBC	BREEAM	Green Globes	LEED	NABERS	CASBEE	ENVEST	ATHENA	ECO-QUANTUM	Ecoprofile	BEAT	GreenCalc	BEES	LCAid
Level	Building	Building	Building	Building	Building	Building	Building	Building/ product	Building product	Building	Building/ product	Building	Building product	Building

Weighting

Weighting is needed to most assessment models, which have various criteria/sub-criteria, to present various criteria as a single value. But there is no homogeneous weighting system to apply all of models. Under the absence of scientifically based weights, some organizations use consensus-based weighting system. In this approach, users or groups to give a weight rank various elements, such as environmental issues, in terms of their relative importance or assign points to these elements. This ranking or scoring is then used to establish weights (Dickie and Howard, 2000).

Various weighting system employed in each model are presented in Table 21.

Table 21 Weighting systems and their transparency

Weighting / Model	Weighting system	Transparency**
GBC	Using default or modified weights by national team to reflect each country's or regional condition	++
BREEAM	Using fixed weight through the national consultative process	--
Green Globes	Based on the UK BREEAM weighting	-
LEED	Using all criteria weighted equally	
NABERS	No weighting	
CASBEE	Using by relative importance value summed up to 1.0	-
ENVEST	Using LCA-based impact assessment (Expert panel method)	-
Athena	No weighting	
ECO-QUANTUM	Using LCA-based impact assessment	+
Ecoprofile	Using fixed weight ranged from1 to 3 (except for energy as 10)	--
BEAT	Using Danish EDIP method	+
GreenCalc	Using TWIN model which is focused on the human health	-
BEES	Using by relative importance value*	++
LCAid	Using LCA-based impact assessment	+

* In BEES, relative importance value can be used by EPA science advisory board study (US EPA, 1990), or Harvard University study (Vicki et al., 1992), or specified by user

** ++very transparent, +relative transparent, -less transparent, --not transparent

THE CASE FOR LCA DESIGN

Limitations of existing models

Fourteen models (including three Australian models) used world wide in relation to environmental assessment of buildings, were compared on the basis of their criteria covered.

The comparison results show that there no complete model satisfied all criteria considered here. Even though GBC scores as a better model of the considered models, it has limitations that it may be more time consuming than others and bring out the difficulties in using the model. Because it is a framework and not a simulation model, users are expected to use other tools to simulate energy performance, estimate embodied energy and emissions, predict thermal comfort and air quality, etc. Although the model is able to assess predicted or potential performance of a building before occupancy, it is not intended to assess performance during operational conditions (NRC, 2001).

In relation to LEED and BREEAM models, Cole and Larsson (1997) pointed out the limitation that these models are not structured to handle different levels of assessment due to difficulties in simplifying. Also, these models were not explicitly designed to handle regional-specific issues, i.e. the systems were not originally designed to accommodate national or regional variations. Especially in the LEED model, Todd et al (2001) described the specific limitation that the criteria in LEED are not applicable to certain types of locations and LEED does not include explicit weighting because of a lack of consensus on appropriate weights (Todd et al., 2001).

These limitations described above are matched with the comparison results here as follows.

In the assessment level, even though some models included some criteria such as commuting transport in GBC and sustainable cities in LEED, which might be included in community level, all of the models considered here remained at the building assessment level except for BEES and Eco-quantum, which focused on building products. It is necessary to extend the assessment level of each model into the broader community level.

In criteria covered by each model, all of models did not include the social concerns, which is one of sustainable criteria suggested by Coles et al (2000) for sustainable building assessment. All real-world design/assessment decisions should operate within an economic aspect that must be considered in conjunction with the other objective criteria, but most models compared excluded the economic aspect except for BEES and LCAid. Most models emphasize environmental loadings such as global warming, indoor air quality as well as energy and resource consumptions.

Whilst LEED, BREEAM and NABERS include broad criteria with simple checklists, which contain site selection, water efficiency, building reuse, or indoor environmental quality control energy that are easily to be easily accessible by architects or constructors, it may be considered as being a more familiar model to building designer, architect or constructor. The checklists in these models are fixed, however, and thus these cannot be modified by regional differences or users' concerns.

For the weighting method for each model compared here, most models give all criteria equal weight partially due to the difficulty of assigning weight to criteria (LEED) or fixed weight which cannot reflect relative importance between criteria due to regional differences or conditions (BRREAM, Ecoprofile). GBC and BEES employ a flexible weighting method, which can include a weight by each user appropriate to their regions or conditions.

All existing models reviewed in this report contribute to environmental assessment of building during the life cycle with different degrees of success and thus help the user to get more familiar with their assessment results. However, several remarks can be made which can lead to improving the effectiveness and sustainable criteria of the models. These models should be improved on in the following aspects:

- Some models are limited to several aspects and cannot be used to evaluate the other various aspects (e.g. BEES and Eco-Quantum only focus on the environmental impact of building products). Thus, a more comprehensive assessment model, extended to include building or community level, is needed.
- Most models do not have the ability of in-depth and elaborate assessment (i.e. they do not have the ability to check different alternative criteria at the same time).
- Some models need a special educated assessor and thus cannot be used by different parties (e.g. BREEAM needs such assessor to use it).
- Some models are time-consuming and require much effort to input data (i.e. GBC is required to use other tools for input data). A new user-oriented model is needed to provide a more convenient model which is easily handled.
- Most models regionally cannot be applied to Australia and thus a new model is needed to adequately apply to regional Australia.
- Most models did not consider the economic aspect, which must be considered in the assessment criteria. The exceptions are BEES, Eco-quantum and LCAid.
- Most models do not use a transparent weighting system and some models use equal or fixed weighting which may lead to misconstrued results. Thus, a new model is needed to allow the transparent weighting system considering the various assessment criteria.

Data from CAD

One of the great disadvantages of environmental assessment procedures for buildings, or indeed any system, is the need to quantify and enter data about a building into the assessment process. This can be very time consuming and as a design progresses the updating of data and tracking of changes can become onerous and error prone. Automation of data entry and utilising existing sources of information are of key importance if automatic assessment is to be achieved. Traditionally, CAD drawings have been simple line views of a building with no associated information as to what the lines actually represent, that is, walls, windows, roofs, etc. However, object orientated CAD systems do contain such information and provide the opportunity to develop automated analysis software.

The Industry Foundation Classes (IFCs) currently being developed and implemented world-wide for information exchange from proprietary CAD systems is the future of data transfer platforms. The IFCs are a set of electronic specifications that represent objects that occur in constructed facilities (including real things such as doors, walls, fans, etc. and abstract concepts such as space, organization, process etc.).

Each specification is called a 'class' which describes a range of things that have common characteristics. Door and window are names of classes which are termed Industry Foundation Classes or IFCs. The major advantage of utilising IFC technology is that it allows analysis of drawings produced from any IFC compliant system. Identification of every object in a CAD drawing by class allows analytical software calculating building performance measures to obtain almost all of the required details directly from the CAD drawing.

Default reasoning rules

Default reasoning rules provide the link between the components in the CAD building model database and the resource usage and emissions of the materials. Thus it will be a requirement that all default reasoning rules should be specified in terms of “known” components (i.e. components specified in the IFC schema) and “known” materials (i.e. materials specified in the materials database) in order to gain a comprehensive environmental model of the building.

In order to cope with the varying level of detail through the subsequent stages of building design, the default reasoning rules must always be defined down to the finest level of detail specified by the materials inventory. This can be achieved by specifying a rule in terms of applicable rules at the next finer level of detail until the rules at the "leaf nodes" are specified in terms of some specific material (or materials) only. In practice a generic set of default reasoning rules would be modified and augmented for any specific project to allow for regional, commercial or regulatory differences.

Desired features

A comparison of the desired features of the proposed environmental assessment tool and the capabilities of existing us shown in Table 22. The assessment tool would be a significant advancement on current tools.

Table 22 Environmental appraisal tool features

Characteristic	CRC Automated Eco-Efficiency Design Tool for Commercial Buildings	Environmental Ratings Systems for Commercial Buildings*
Quantification	Absolute values	Relative values (usually ordinal scaling)
	Evidence based calculation (repeatable)	Evidence interpretation required (individual assessment)
	Calculated from building components	Calculated from aggregate building description
	Includes full life cycle	Includes some life cycle allowances
	Includes costing	No costing included
	Aggregates values upwards from components	Available at building level only
Assessment	Objective (no personal judgment required)	Subjective (personal judgment required with some objective measures obtained using other tools)
	Comparative ratings star rating levels	Comparative ratings at star rating level
	Evaluation at detailed environmental impacts level	No detailed evaluation
	Comparison of performance of components	No comparison of performance of components
	Accepted for standards, codes, performance based tests	Accepted for overall assessments
	Variety of performance measures available	Usually single measure or rating only
	Weighting of components transparent to user	Inherently assumed weighting of components
Tools	Data direct from CAD	Data entered from collated information
	Evaluation based on comprehensive databases	Evaluation done by guided individual judgment
	Full evaluation at sketch design stage	Usually fully applied at sketch design stage
	Full evaluation at detailed design stage	Little further practical use at detailed design stage
	Process can be verified at every level	Process can be verified assuming subjective assessments
	Tradeoffs easily accomplished with tool	Tradeoffs usually accomplished by hand
	Extensive calculations only possible with tool	Can be assessed by questionnaire

* e.g. LEED, BREEAM, NABERS, Envest, LCAid

Outline of LCA Design

The objective is to develop a material analysis decision-support system which interfaces to IFC complaint CAD software for environmental and cost assessments of commercial building designs.

The outline of the approach to be used in LCA Design is shown in Figure 4. The steps in the process of calculating an environmental impact assessment are:

6. Obtain the plans of the building
7. Create a 3D CAD object model of the building.
8. Extract the drawing data into an industry standard file describing all the objects in the drawing as an Industry Foundation Classes (IFC) file (compatible with several 3D CAD packages).
9. Calculate the environmental emissions, resource usage and energy in creating the materials in the building from the IFC database, the databases of environmental impact of materials and the generic default reasoning rules relating the materials to objects.
10. Display the results such as performance indicators, impact breakdowns, etc for the users to analyse..

To be able to quantify the environmental impact of materials consumed in the construction of a building, the quantities of materials must first be estimated through a process of disaggregation to a level of detail which allows for the separation of components into their principal materials. Environmental impacts of each material can then be multiplied by the quantities of individual materials and the products aggregated to obtain the total for each material, element or whole building. A consistent and reliable database of resource usage and environmental emissions to the environment generated by the extraction and manufacture of building materials will be expanded to cover all necessary building materials in stages.

The chosen approach to fast and practical estimates of environmental impacts directly from 3D CAD drawings at the design stage requires 3D CAD objects, accurate quantity functions and generic materials formulas.

The calculated resource usage and emissions will then be combined to estimate the totals in various categories of emissions etc. Tables and graphs to readily analyse the data will be provided.

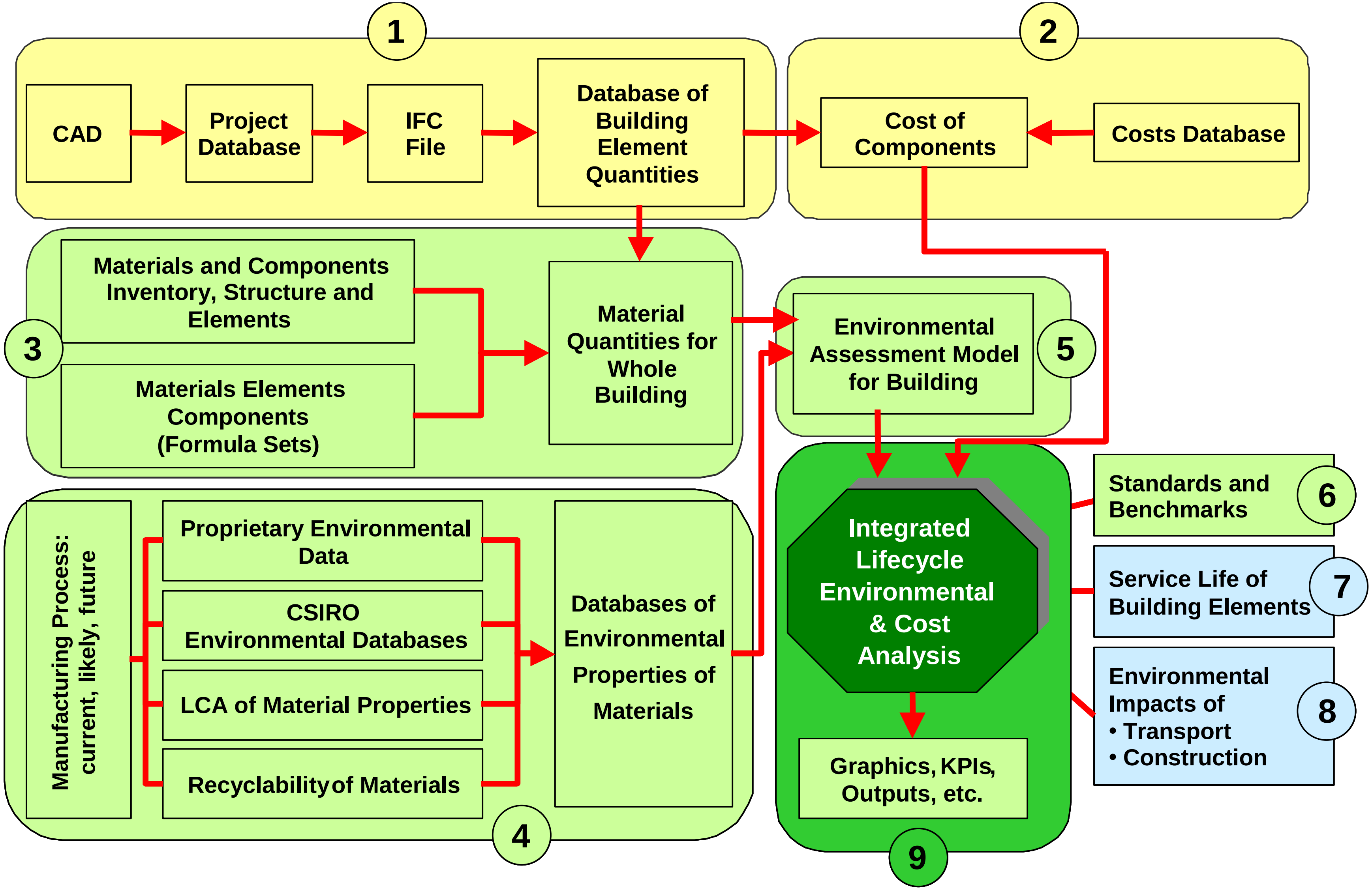

Figure 2 Components of the proposed Integrated Lifecycle Environmental and Cost Analysis model

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Appendix A - LEED credit checklist

Sustainable Sites		**14 points**
Prerequisite 1	Erosion & Sedimentation Control[+1]	Required
Credit 1	Site Selection	1
Credit 2	Urban Redevelopment	1
Credit 3	Brownfield Redevelopment	1
Credit 4.1	Alternative Transportation, Public Transportation Access	1
Credit 4.2	Alternative Transportation, Bicycle Storage & Changing Rooms	1
Credit 4.3	Alternative Transportation, Alternative Fuel Refuelling Stations	1
Credit 4.4	Alternative Transportation, Parking Capacity	1
Credit 5.1	Reduced Site Disturbance, Protect or Restore Open Space	1
Credit 5.2	Reduced Site Disturbance, Development Footprint	1
Credit 6.1	Stormwater Management, Rate or Quantity	1
Credit 6.2	Stormwater Management, Treatment	1
Credit 7.1	Landscape & Exterior Design to Reduce Heat Islands, Non-Roof	1
Credit 7.2	Landscape & Exterior Design to Reduce Heat Islands, Roof	1
Credit 8	Light Pollution Reduction	1
Water Efficiency		**5 points**
Credit 1.1	Water Efficient Landscaping, Reduce by 50%	1
Credit 1.2	Water Efficient Landscaping, No Potable Use or No Irrigation	1
Credit 2	Innovative Wastewater Technologies	1
Credit 3.1	Water Use Reduction, 20% Reduction	1
Credit 3.2	Water Use Reduction, 30% Reduction	1
Energy & Atmosphere		**17 points**
Prerequisite 1	Fundamental Building Systems Commissioning[+2]	Required
Prerequisite 2	Minimum Energy Performance[+3]	Required
Prerequisite 3	CFC Reduction in HVAC&R Equipment[+4]	Required
Credit 1.1	Optimise Energy Performance, 20% New / 10% Existing	
Credit 1.2	Optimise Energy Performance, 30% New / 20% Existing	
Credit 1.3	Optimise Energy Performance, 40% New / 30% Existing	
Credit 1.4	Optimise Energy Performance, 50% New / 40% Existing	
Credit 1.5	Optimise Energy Performance, 60% New / 50% Existing	
Credit 2.1	Renewable Energy, 5%	
Credit 2.2	Renewable Energy, 10%	
Credit 2.3	Renewable Energy, 20%	
Credit 3	Additional Commissioning	
Credit 4	Ozone Depletion	
Credit 5	Measurement & Verification	
Credit 6	Green Power	
Materials & Resources		**13 points**
Prerequisite 1	Storage & Collection of Recyclables[+5]	Required
Credit 1.1	Building Reuse, Maintain 75% of Existing Shell	1
Credit 1.2	Building Reuse, Maintain 100% of Shell	1
Credit 1.3	Building Reuse, Maintain 100% Shell & 50% Non-Shell	1
Credit 2.1	Construction Waste Management, Divert 50%	1
Credit 2.2	Construction Waste Management, Divert 75%	1
Credit 3.1	Resource Reuse, Specify 5%	1
Credit 3.2	Resource Reuse, Specify 10%	1
Credit 4.1	Recycled Content, Specify 25%	1
Credit 4.2	Recycled Content, Specify 50%	1
Credit 5.1	Local/Regional Materials, 20% Manufactured Locally	1
Credit 5.2	Local/Regional Materials, of 20% Above, 50% Harvested Locally	1
Credit 6	Rapidly Renewable Materials	1
Credit 7	Certified Wood	1

Indoor Environmental Quality		**15 points**
Prerequisite 1	Minimum IAQ Performance[+6]	Required
Prerequisite 2	Environmental Tobacco Smoke (ETS) Control[+7]	Required
Credit 1	Carbon Dioxide (CO2) Monitoring	1
Credit 2	Increase Ventilation Effectiveness	1
Credit 3.1	Construction IAQ Management Plan, During Construction	1
Credit 3.2	Construction IAQ Management Plan, Before Occupancy	1
Credit 4.1	Low-Emitting Materials, Adhesives & Sealants	1
Credit 4.2	Low-Emitting Materials, Paints	1
Credit 4.3	Low-Emitting Materials, Carpet	1
Credit 4.4	Low-Emitting Materials, Composite Wood	1
Credit 5	Indoor Chemical & Pollutant Source Control	1
Credit 6.1	Controllability of Systems, Perimeter	1
Credit 6.2	Controllability of Systems, Non-Perimeter	1
Credit 7.1	Thermal Comfort, Comply with ASHRAE 55-1992	1
Credit 7.2	Thermal Comfort, Permanent Monitoring System	1
Credit 8.1	Daylight & Views, Daylight 75% of Spaces	1
Credit 8.2	Daylight & Views, Views for 90% of Spaces	1
Innovation & Design Process		**5 points**
Credit 1.1	Innovation in Design: Specific Title	1
Credit 1.2	Innovation in Design: Specific Title	1
Credit 1.3	Innovation in Design: Specific Title	1
Credit 1.4	Innovation in Design: Specific Title	1
Credit 2	LEED™ Accredited Professional	1
Total		**69 points**
Certified: 26-32 points, Silver: 33-38 points, Gold: 35-91 points, Platinum: 52-69 points		

+1 Intent is to control erosion to reduce negative impacts on water and air quality

+2 Intent is to verify and ensure that fundamental building elements and systems are designed, installed and calibrated to operate as intended.

+1 Intent is to control erosion to reduce negative impacts on water and air quality

+2 Intent is to verify and ensure that fundamental building elements and systems are designed, installed and calibrated to operate as intended.

+3 Intent is to establish the minimum level of energy efficiency for the base building and systems

+4 Intent is to reduce ozone depletion

+5 Intent is to facilitate the reduction of waste generated by building occupants that is hauled to and disposed of in landfills

+6 Intent is to establish minimum indoor air quality (IAQ) performance to prevent the development of indoor air quality problems in buildings, maintaining the health and well being of the occupants

+7 Intent is to prevent exposure of building occupants and systems to environmental tobacco smoke

Appendix B - BEES weighting systems

EPA Science Advisory Board (SAB) study weighting method

In 1990, the EPA's Science Advisory Board (SAB) developed a list of the relative importance of various environmental impacts to help EPA best allocates its resources. The following criteria were used to develop the lists:

- The spatial scale of the impact
- The severity of the hazard
- The degree of exposure
- The penalty for being wrong

Nine of the ten BEES impact categories were among the SAB lists of relative importance (US EPA 1990).

Relatively high-risk problems: global warming, indoor air quality, ecological toxicity, human toxicity, ozone depletion, and smog

Relatively medium-risk problems: acidification, eutrophication

Relatively low-risk problems: sold waste

Verbal importance rankings, such as "relatively high-risk", may be translated into numerical importance weights by following guidance provided by a MADA method known as the Analytic Hierarchy Process (AHP). The AHP methodology suggests the following numerical comparison scale:

1 Two impacts contribute equally to the objective (in this case environmental performance)

3 Experience and judgement slightly favour one impact over another

5 Experience and judgment strongly favour one impact over another

7 One impact is favoured very strongly over another, its dominance demonstrated in practice

9 The evidence favouring one impact over another is of the highest possible order of affirmation

2, 4, 6, and 8: When compromise between values of 1, 3, 5, 7 and 9 is needed.

Through an AHP process known as pair-wise comparison, numerical comparison values are assigned to each possible pair of environmental impacts. Relative importance weights can then be derived by computing the normalized eigenvector of the largest eigenvalue of the matrix of pair-wise comparison values.

The following Tables list pair-wise comparison values assigned to the SAB verbal importance rankings, and the resulting importance weights computed for the BEES impacts, respectively.

Pair-wise comparison values for deriving impact category importance weights.

Verbal importance comparison	Pair-wise comparison value
High vs. Medium	2
Medium vs. Low	4
High vs. Low	4

Relative importance weights based on Science Advisory Board Study.

	Relative importance weight (%)		
Impact category	**6 Impacts**	**7 Impacts***	**10 Impacts***
Global warming	27	21	13
Acidification	13	11	6
Eutrophication	13	11	6
Natural resource depletion	13	11	6
Indoor air quality	27	21	13
Solid waste	7	4	4
Smog	-	21	13
Ecological toxicity	-	-	13
Human toxicity	-	-	13
Ozone depletion	-	-	13

*This set of expanded impacts is available for a limited number of BEES products

Harvard University study

In 1992, an extensive study was conducted at Harvard University to establish the relative importance of environmental impacts (Lippiat, 2000). The study developed separate assessments for the United States, The Netherlands, India, and Kenya. In addition, separate assessments were made for "current consequences" and future consequences" in each country. For current consequences, more importance is placed on impacts of prime concern today. Future consequences places more importance on impacts that are expected to become significantly worse in the next 25 years.

Nine of the ten BEES impact categories were among the studied impacts. The following table shows the current and future consequence rankings assigned to these impacts in the United States. The study did not explicitly consider solid waste as an impact. For this exercise, solid waste is assumed to rank low for both current and future consequences, based on other relative importance lists.

US ranking for current and future consequences by impact category.

Impact category	Current consequences	Future consequences
Global warming	Low	High
Acidification	High	Low
Eutrophication	Medium	Medium
Natural resource depletion*	Medium	Medium-low
Indoor air quality	Medium	Low
Smog	High	Low
Ecological toxicity	Medium-low	Medium-low
Human toxicity	Medium-low	Medium-low
Ozone depletion	Low	High

*Average of consequences for hazards contributing to natural resource depletion.
Vicki Norberg-Bohrn et al. (1992)

Verbal importance ranking from the Harvard study (Vicki et al, 1992) are translated into numerical, relative importance weights using the same, AHP-based numerical comparison scale and pair-wise comparison process described above for the SAB study. Sets of relative importance weights are derived for current and future consequences, and then combined by weighting future consequences as twice as important as current consequences. Following table lists the resulting importance weights for the ten BEES impacts. The combined importance weight set is offered as an option in the BEES model. However, the BEES user is free to use the current or future consequence weight sets by entering these weights under the user-defined software option.

Relative importance weights based on Harvard University study

Relative importance weight set									
	Current (%)			**Future (%)**			**Combined (%)**		
Impact category	6	7*	10*	6	7*	10*	6	7*	10*
Global warming	8	6	5	38	35	22	28	25	16
Acidification	33	25	19	10	9	6	17	15	10
Eutrophication	16	12	9	19	18	11	18	16	10
Natural resource depletion	16	12	9	14	13	8	15	13	9
Indoor air quality	16	12	9	10	9	6	12	10	7
Solid waste	11	8	7	9	8	5	10	8	6
Smog		25	19		7	5		13	10
Ecological toxicity			9			8			8
Human toxicity			9			9			9
Ozone depletion			5			20			15

*This set of expanded impacts is available for a limited number of BEES products.

Appendix C - Ecoprofile sub-components

Sub-components and parameters in "External environment" component of Ecoprofile

Sub-components	**Parameters**
Release to air	Type of heating installation
	Service of heating installation
	Refrigerant in heat pump/cooling installation
Release to ground	Pollutants in the ground
Release to water	Management of surface water
Waste management, toxic and environmentally hazardous substances	Demolition waste
	Availability of source-sorting of waste
	Waste room
	Waste compactor
	Kitchen waste
	Use of disposable products
	Organic waste from outside areas
	Routines for registration of environmentally dangerous substances
	PCB
	Asbestos
	Other environmentally hazardous substances
Outside areas	Natural resources and biological diversity
	High voltage lines
	Maintenance of external facades of building
Transport	Possibility of bicycle use
	Bicycles available for internal use
	Nearness to public transportation
	Frequency of departures
	Shipping of goods

Sub-components and parameters in “Resource” component of Ecoprofile

Sub-components		Parameters
Energy	Flexibility	Type of heating installation and heating source
	Energy use	
	Real energy consumption	Measured consumption compared to “normtall”
	Technical condition	
	Heating	U-values for walls, floor and ceiling
		U-values for windows
		Heater/heat exch. Condition (efficiency)
		Pip isolation
		Regulation of plant
		Thermostatic radiator vents
		Night-/weekend lowering of temperature
		Regulation of room temperature
		Tap water
	Ventilation	Condition of installations
		Heat recovery
		Time controlled
		Isolation of pipes and ducts
	Cooling	Locking over hating installation
		Sun shades toward the south/east/west
		Free cooling
		Regulation
	Lighting	Lighting in offices and common areas
		Control of lighting
	Outdoors	Lighting
		Warming cables (sidewalk and gutters)
	Operation	Training of operators
		Operation and maintenance instructions
		Routines for operation and maintenance
		Service agreements
		Energy monitoring system (EOS)
Water	Water consumption	Water consumption
		Water-conserving equipment
		Leaks
Land		No parameters yet
Materials		No parameters yet

Sub-components and parameters in “Indoor climate” component of Ecoprofile

Sub-components	**Parameters**
Thermal climate	Thermal climate is simulated with the help of computer program indoor climate in office buildings (IMK)
Atmospheric climate	Atmospheric climate is classified from a matrix that includes the following parameters:
	Perceived air quality
	Emission factor for floor
	Emission factor for walls
	Emission factor for ceiling
Acoustic climate	Acoustic climate is classified from a matrix that includes the following parameters:
	Maximum noise from the technical installations (dBA)
	Sound absorbing area in the ceiling in cell offices and landscape offices
	Possibility of overhearing between office work stations
Actinic climate	Actinic climate (light and radiation conditions) are classified from a matrix that includes the following parameters:
	Daylight and blending possibilities
	Lighting level (Lux)
	Type of lighting installation
Mechanical climate	Mechanical climate is classified from a matrix that includes the following parameters:
	Furniture density in offices (risk)
	Lowered data screens (ergonomy)
	Support for forearms at keypads (ergonomy)
Cross factors ventilation	Sub-criteria “ventilation” is classified from a matrix that includes the following parameters:
	Balance of ventilation system
	Placement of fresh air intake
	Filtration of supply air
	Recirculation of exhaust air to intake
	Number of years since the last cleaning of duct network
Cleaning	Sub-components “Cleaning is classified from a matrix that includes the following parameters:
	Shelf factor
	Fluff factor
	Ceiling panel density
	Cleaning frequency of flow
Moisture	Sub-component “Moisture” is classified from a matrix that includes the following parameters:
	Number of incidents of moisture damage in the last year
	Water damage protection of pipe installation
	Staining/discoloration or blistering

Appendix D - NABERS rating headings and subheadings

Headings and subheadings of NABERS Commercial

Headings	Subheadings
Land	Nature of site (building) for buildings under three years old
	Total site area per m^2 of building total floor area (building)
	Total site area per building user (building)
	Area of site planted with beneficial plants (user)
	Impermeably paved area of the site (building/user)
Materials	Cost of building per m^2 of floor area (building)
	Materials types for structure, walls, floors and roofs (building) for buildings under three years old
	Building age (building) for buildings over three years old
	Time since last major internal re-fit (user) for buildings over three years old
Energy	Energy efficiency – total energy consumption in kWh/m^2
	Greenhouse emissions of the whole building (building/user)
	Greenhouse emissions for high performance buildings (building/user)
	Renewable electricity use (user)
	Building that generate more energy than they use (building)
Water	Water consumption (for whole site) from public supply per person (user)
	Source of on-site water supply (building)
Interior	Nature of internal fit-out, equipment and operation (building/user)
	Percentage of workplaces within 5 meters of a window (building)
	Percentage of workers able to control light levels at their workplace (building)
Resources	Total building area per person (building)
	Intended use of building – number of hours per day (user)
	Intended use of building – number of weeks per year (user)
Transport	Distance to nearest local shop (building)
	Distance to nearest urban center (building)
	Number of car park spaces provided on site (building)
	Distance to public transport (building)
	Provision of bicycle facilities (building)
Waste	Provision of on-site recycling facilities (building/user)
	Provision of local collection for recyclables (building)
	Wastewater re-use (building)
	Use of more sustainable sewage treatment system (building)

Total possible score 150 stars for both recent and older buildings

Headings and subheadings of NABERS Domestic

Headings	Subheadings
Land	Nature of site (building) for buildings under three years old
	Total site area per m^2 of building total floor area (building)
	Total site area per person (building)
	Area of site planted with beneficial plants (user)
	Impermeably paved area of the site (building/user)
Materials	Cost of building per m^2 of floor area (building)
	Materials types for structure, walls, floors and roofs (building) for buildings under three years old
	Building age (building) for buildings over three years old
	Time since last major internal renovation (user) for buildings over three years old
Energy	Energy efficiency – total energy consumption in kWh/m^2
	Greenhouse emissions of the whole building (building/user)
	Greenhouse emissions for high performance buildings (building/user)
	Renewable electricity use (user)
	Building that generate more energy than they use (building)
Water	Water consumption (for whole site) from public supply per person (user)
	Source of on-site water supply (building)
Interior	Nature of internal fit-out, appliances and operation (building/user)
Resources	Total building area per person (building)
	Intended use of building – number of weeks per year (user)
Transport	Distance to nearest local shop (building)
	Distance to nearest local supermarket/bank/post office (building)
	Distance to nearest urban center (building)
	User of alternative means of transport for the journey to work and school (user)
	Total number of cubic centimeters of engine capacity per occupant (user)
	Annual kms driven per household (user)
Waste	Use of on-site composting facilities (user)
	Provision of on-site recycling facilities (building/user)
	Provision of local collection for recyclables (building)
	Use of more sustainable sewage treatment system (building)

Total possible score 140 stars.

Appendix E - Environmental assessment databases

Comparison of existing life cycle inventory database systems

Current life cycle inventory databases used internationally include:

- Boustead
- BUWAL
- ETH
- ATHENA
- DEAM (EU)
- LCAiT
- LIMS
- PIA
- KCL-CODATA

Current life cycle inventory databases with Australian data include:

- Australian LCI (RMIT)
- LISA
- LCAid

Of these databases, LCAiT, LIMS, PIA, and KCL-CODATA, were not considered in depth for of the following reasons:

- LCAiT contains a limited number of chemicals, plastics, pulp and paper products, which are focused on the data for packaging in Sweden (Hemming, 1995). In addition, most of data are referred from another source, like BUWAL or Boustead. The time scope is outdated, being from the 1980s and 1990s.
- LIMS (Life Cycle Interactive Modeling System) data is focused only on U.S.A regionally and some data are corrected but based on uncertain information.
- PIA, developed by TME (Institute voor Toegepaste Milieu Economie), is limited to Netherlands and Swiss regionally. Also, most of data are based on the 1988 and 1990 and are thus now outdated.
- KCL-ECODATA, developed by Finnish Pulp and Paper Research Institute (KCL), mainly focused on the pulp or related products. In addition, the regional scope is confined to Finland and central Europe.

Therefore Boustead, BUWAL, ETH, ATHENA, and DEAM (EU) only are considered for comparison. The Australian LCI database (RMIT), LISA, and LCAid are included in the comparison.

Criteria for comparison

For the overall database comparison, the following criteria were considered (Table 23):

- Items which are included in the databases
- Geographic boundary (Regional scope)
- Time scope
- Input/Output items (environmental emissions/resource consumption)
- Cost

For the comparison of the contents of each database for building materials, the following criteria were considered (Table 24):

- Stone
- Cement
- Concrete
- Steel
- Aluminium
- Plastics
- Brick
- Glass
- Textile
- Paints
- Wood (hard/soft)

For the comparison of the contents of each database for energy and processes, the following criteria were considered (Table 25):

- Fuel
- Electricity
- Transport
- Waste Treatment

For the comparison of the environmental impacts in selected databases, the following criteria were considered:

- Natural resource consumption (Table 26)
- Airborne emissions (Table 27)
- Waterborne emissions (Table 28)
- Solid emissions (Table 29).

Table 23 Comparison of selected databases

Database	Boustead	BUWAL	ETH (Ecoinvent)	ATHENA	DEAM	RMIT	LISA	LCAid
Nation	U.K	Swiss		Canada	U.K	Australia		
Item	2500 operations (processes)	packaging materials	2000 processes*	building materials**	700 module (=product)	30 products	building materials	
Regional scope	Europe (including Australia for fuel)	Switzerland, Europe		North America	North America, Europe	Australia		
Time	96-99	88-90	96-99	92-99	91-98	N/A		
Input/Output	80 to resources	300 kinds of environmental emissions /resources consumption	200 to resources	Embodied energy, Global warming potential, Pollutants to air, Pollutants to water, Solid wastes emission	34 to resource	30 to resource	Energy, NMVOC, GHG, NOx, SOx, SPM	Water, energy
	80 to air		230 to air		100 to air	100 to air		24 to air
	60 to water		170 to water		100 to water	80 to water		10 to water
	33 to wastes		130 to soil, 40 to wastes		20 to soil, 20 to wastes	20 to wastes		4 to wastes
Cost	£10 000 per annum	170 CH fr	EUR 1200	Membership 10000 Canada $	160 A$/module	Free	free	N/A
Note	Available at £ 2,500		Available from Spring 2003				Not DB but Tool	

* included 100 types of building materials

** 16 wooden products (updated '99), 17 steel products (92-95), 8 concrete products (updated '99), 14 cladding products (95-98), 10 Gypsum Wallboard and Finishing Materials (96), 7 Insulation and Vapour Barriers (updated '99), residential & commercial roofing, 4 Windows & Glazed Curtain wall (updated '99), 3 Paint Finishes (98).

Boustead: www.boustead-consulting.co.uk
BUWAL: http://www.buwal.ch/e/themen
ETH: www.ecoinvent.ch
ATHENA: www.athenasmi.ca/mem_prog/mem_program.htm
DEAM: www.ecobilan.com/services/deam/gb_deamidx.html
RMIT: www.cfd.rmit.edu.au/lca/LCAframe3.html (most of data are secondary data sources)
LISA: www.lisa.au.com/
LCAid: www.projectweb.gov.com.au/dataweb/lcaid/

Table 24 Contents of each database for building materials

		Boustead	BUWAL (ETH)		ATHENA	DEAM	RMIT	LISA	LCAid
Nation		U.K	Swiss		Canada	U.K	Australia		
Region covered		Europe	Europe		N.A	N.A /Europe	Australia		
Stone	Gravel	√		√				√	
	Sand	√		√		√			
	Others	√		√		√			
Cement	Average	√		√	√	√	√		
	Cement products	√		√	√			√	
Concrete	Average					√	√		
	Various type	√		√	√			√	V
	Concrete products	√		√	√				V
Steel	Average						√		
	Various type	√		√	√	√		√	
	Other steel products	√		√	√	√			V
Aluminum	Average						√	√	V
	Various type	√	√	√	√	√			
	Other aluminum products		√	√	√	√			
Plastics	Average								
	Various type	√	√	√		√	√	√	
	Other plastic products	√	√	√		√			V
Brick	Average								
	Various type	√		√	√			√	V
	Other brick products	√		√	√			√	
Glass	Average						Bottle		V
	Various type	√	√	√	√	√		√	
	Other glass products	√	√	√	√				
Textile	Average								
	Various type	√		√					
	Other textile products								
Paints	Average								V
	Various type	√		√	√	√		√	
Wood (hard/soft)	average								
	Various type	√	√	√	√	√		√	V
	Other wooden products	√		√	√				V
Other building materials		V		√	√			√	

N.A: North America
Boustead: DB description of Boustead Consulting Limited: www.boustead-consulting.co.uk/database.htm)
BUWAL: http://www.buwal.ch/e/themen/
ETH: private communication (Mr.Hans-Joerg Althaus; Hans-Joerg.Althaus@empa.ch)
ATHENA: Athena database description from website (www.athenasmi.ca/database/db-main.htm)
DEAM: TEAM software
RMIT: www.cfd.rmit.edu.au/lca/LCAframe3.html
LISA: www.lisa.au.com/
LCAid: www.projectweb.gov.com.au/dataweb/lcaid/
ETH database: Presently not available (will be released from spring 2003)

Table 25 Contents of each database for energy and process

		Boustead	BUWAL (ETH)		ATHENA	DEAM	RMIT	LISA	LCAid
Nation		U.K	Swiss		Canada	U.K	Australia		
Region		Europe	Europe		N.A	N.A/ Europe	Australia		
Fuel	propane	√		√		√	√		
	petroleum	√	√	√		√	√	√	
	diesel	√		√		√	√	√	
	natural gas	√	√	√		√	√	√	√
	coal	√	√	√		√	√		
Electricity	average	√				√	√	√	√
	by state						√		
Transport	private car	√		√		√			
	road transport	√	√	√		√	√		
	rail transport	√	√	√		√	√	√	
	river/sea transport	√	√	√		√	√	√	
	air transport	√		√		√	√		
	others								
Waste Treatment	recycle	√	√	√		√		√	
	incineration	√	√	√		√			
	landfill	√	√	√		√		√	
Others		√	√	√		√		√	√

N.A: North America
Boustead: DB description of Boustead Consulting Limited: www.boustead-consulting.co.uk/database.htm)
BUWAL: http://www.buwal.ch/e/themen/
ETH: private communication (Mr.Hans-Joerg Althaus; Hans-Joerg.Althaus@empa.ch)
ATHENA: Athena database description from website (www.athenasmi.ca/database/db-main.htm)
DEAM: TEAM software
RMIT: www.cfd.rmit.edu.au/lca/LCAframe3.html
LISA: www.lisa.au.com/
LCAid: www.projectweb.gov.com.au/dataweb/lcaid/
ETH database: Presently not available (will be released from spring 2003)

Table 26 Environmental impacts in selected databases – resource consumption

		Boustead[1]	BUWAL[2]	ATHENA[3]	DEAM[4]	RMIT[5]	LISA[6]	LCAid[7]
Natural Resource	Air	√				√		
	barrium sulphate (BaSO4)	√			√			
	Bauxite	√	√		√	√		
	Bentonite	√	√		√	√		
	Biomass	√				√		√
	Calcium sulphate (CaSO4)	√			√			
	clay	√			√	√		
	Coal	√	√		√	√		√
	Chromium (Cr, ore)	√	√		√			
	Copper (Cu, ore)	√						
	crude oil	√	√		√	√		√
	dolomite	√				√		
	electricity	√	√		√		√	
	ferromanganese	√				√		
	fertiliser					√		
	gravel	√			√	√		
	iron (ore)	√	√		√	√		
	land				√	√		
	Lead (Pb, ore)	√			√			
	lignite	√			√	√		√
	limestone	√	√		√	√		
	Sodium Chloride (NaCl)	√			√	√		
	Nickel (Ni, ore)	√			√			
	natural gas	√	√			√		√
	pot. energy hydropower	√				√		√
	sand	√			√	√		
	Uranium (U, ore)		√		√			
	water	√	√		√	√	√	√
	wood	√	√		√			√
	Zinc (Zn, ore)	√	√		√			

1: I/O data obtained from Boustead Model DB demo version
2: I/O data for Tinplate obtained from website: www.ecosite.co.uk/buwal.htm
3: Not available
4: I/O data for Steel obtained from TEAM software
5: I/O data for Tinplate (20% steel scrap) obtained from website: www.cfd.rmit.edu.au/lca/datadownloads.html
6. I/O data obtained from LISA tool software: http://www.lisa.au.com
7. I/O data obtained from website: http://www.projectweb.gov.com.au/dataweb/lcaid/

Table 27 Environmental impacts in selected databases – airborne emissions

		Boustead[1]	BUWAL[2]	ATHENA[3]	DEAM[4]	RMIT[5]	LISA[6]	LCAid[7]
Airborne Emission	Antimony (Sb)	√			√	√		
	(a) Ammonia (NH3)	√	√		√			√
	As	√			√	√		
	B				√	√		
	benzene		√		√	√		
	Cd	√	√		√	√		
	Cl2	√			√	√		
	CO	√	√		√	√		
	CO2	√	√		√	√	√	√
	Cr	√	√		√	√		
	Cr (III)	√			√	√		
	Cr (VI)	√			√	√		
	Cu	√	√		√	√		
	Cyanide (CN)		√		√	√		
	dioxin				√	√		
	dust	√	√			√	√(SPM)	√
	fluorine (F)	√			√	√	`	
	H2	√				√		
	H2S	√	√			√		
	HCl	√	√		√	√		√
	hexane					√		
	Hydrogen Fluoride	√	√		√			√
	hydrocarbons	√	√			√		
	Iron (Fe)	√			√			
	metals	√	√		√			√
	methane	√	√		√	√		√
	Methanol (CH3OH)				√			
	mercaptane	√				√		√
	Mg				√	√		
	Mn		√		√	√		
	Mo				√	√		
	N2O	√	√		√	√		√
	n-Hexane					√		
	Ni	√	√		√	√		
	Nox	√	√		√	√	√	√
	Pb	√	√		√	√		√
	Selenium (Se)	√			√	√		
	SOx	√	√		√	√	√	√
	thallium (Tl)		√		√			
	V		√		√	√		
	VOC	√			√	√	√	√
	xylenes				√	√		
	Zn	√	√		√	√		

1: I/O data obtained from Boustead Model DB demo version
2: I/O data for Tinplate obtained from website: www.ecosite.co.uk/buwal.htm
3: Not available
4: I/O data for Steel obtained from TEAM software
5: I/O data for Tinplate (20% steel scrap) obtained from website: www.cfd.rmit.edu.au/lca/datadownloads.html
6. I/O data obtained from LISA tool software: http://www.lisa.au.com
7. I/O data obtained from website: http://www.projectweb.gov.com.au/dataweb/lcaid/

Table 28 Environmental impacts in selected databases – waterborne emissions

		Boustead	BUWAL	ATHENA	DEAM	RMIT	LISA	LCAid
Waterborne Emission	Acid as H+	√			√	√		
	ammonia	√	√		√	√		√
	antimony (Sb)					√		
	AOX (Adsorbable Organic Halogens)	√	√		√			
	As	√	√		√	√		√
	BOD	√	√		√	√		
	Cadmium (Cd)	√	√		√	√		
	Calcium (Ca++)	√			√			
	Chromium(VI)	√				√		
	Cl-	√	√		√	√		
	Cobalt				√	√		
	COD	√	√		√			√
	Cr	√	√		√	√		
	crude oil					√		
	Cu	√	√			√		√
	CxHy					√		
	cyanide (CN-)	√	√			√		
	dissolved organics	√			√	√		
	Fe++/Fe+++	√	√		√	√		
	fluoranthene					√		
	fluorene	√				√		
	fluoride	√	√		√	√		
	hexachlorobenzene				√	√		
	Hg	√	√		√	`√		√
	metallic ions	√	√		√	√		
	Na	√			√	√		
	Ni	√	√		√	√		√
	nitrate (NO3-)	√	√		√	√		
	oil	√	√		√	√		
	Oils & greases	√	√			√		
	PAH's		√		√	√		
	Pb	√	√		√	√		√
	phenol	√	√		√	√		
	phenolic compounds				√	√		
	Phosphate (PO4 3-)	√	√		√	√		√
	pyrene					√		
	sulphate	√	√		√	√		
	sulphide	√	√		√	√		
	suspended solids	√	√		√	√		
	Total nitrogen		√		√	√		√
	TOC	√	√		√	√		
	toluene		√		√	√		
	xylene				√	√		
	Zn	√	√		√	√		

Table 29 Environmental impacts in selected databases – solid emissions

		Boustead[1]	BUWAL[2]	ATHENA[3]	DEAM[4]	RMIT[5]	LISA[6]	LCAid[7]
Solid emissions	ash	√			√	√		
	industrial waste	√				√		√
	inert chemicals	√	√			√		
	mineral waste	√	√			√		
	mining waste					√		
	produc. waste (not inert)	√				√		
	residue	√			√	√		
	slags/ash	√	√		√	√		
	slurry (thickener)					√		
	solid waste	√			√	√		√
	tailings	√				√		
	unspecified	√			√	√		
	Waste (hazardous)				√			
	Waste: Radioactive				√			
	waste- undefined	√	√			√		
	Waste (total)				√			

1: I/O data obtained from Boustead Model DB demo version
2: I/O data for Tinplate obtained from website: www.ecosite.co.uk/buwal.htm
3: Not available
4: I/O data for Steel obtained from TEAM software
5: I/O data for Tinplate (20% steel scrap) obtained from website: www.cfd.rmit.edu.au/lca/datadownloads.html
6. I/O data obtained from LISA tool software: http://www.lisa.au.com
7. I/O data obtained from website: http://www.projectweb.gov.com.au/dataweb/lcaid/

Comparison method

There are a number of databases for LCA (Life Cycle Assessment) tool.

When comparing the databases related to LCI, users should consider following criteria:

- Items (how many items are included in the database considered),
- Regional scope (what is the regional scope for the database considered),
- Time (how often the database are updated),
- Environmental Input/output (how many environmental input/output items are covered in the database considered),
- Economic (how much the cost for the database considered).
- Transparent
- Representative

In here considering above, five criteria are selected to compare the existing database for the building material/building environmental assessment.

The selected criteria for each database are generally difficult to quantify or give an exact crisp value. Thus, they are assigned linguistic values for the database versus the criteria, such as medium, bad, and good, and then estimated by converting them into numerical values (linguistic values = {Good, Medium, Poor} = {5, 3, 1}). It becomes more meaningful to quantify a subjective measurement into a range rather than in a crisp value. The linguistic value assigned for each database and the numerical numbers corresponding to each linguistic value are shown in Table 30. For the "Items" in Table 30, the databases which have more than 2,000 items are assigned linguistic value as "Good", on the other hand, the databases which have less than 30 items are assigned as "Poor". For the linguistic values of the regional boundary, it is assumed the database which includes Australia as regional boundary is "Good", but not covered Australia as "Poor". For the criteria of environmental emission/resource consumption, the linguistic values are assigned as "Good" for having more than 500 I/O items, and "Poor" for the database having less than 100 items. For the time boundary, the database which updated most recently is assigned as "Good", but the database which have old data is assigned as "Poor". Finally the linguistic value for the cost, database with free of charge or less than A$100 is assigned as "Good", and "Poor" for the database which is needed more than A$4000.

In Table 30, the value of importance for each criterion may vary according to the opinion of different users or society types. Thus, five cases of judgment scale for each criterion were assumed based on possible case (Case A, B, C D, and E). Case A is all criteria as having the same importance. While case B is most concerned about "Items". Case C is most concerned with "Regional Boundary" and case D is most concerned about "Time". And case E is the most concerned to "Cost".

Based on the each type, weightings are given for each of the criterion. When calculating the weightings, it is assumed that the weighting value for the criterion which is most concerned is assigned as 3 or 5, which are used to convert linguistic value into the numerical value above.

Table 30 Scores of life cycle analysis models

Criteria \ Database		Boustead	BUWAL*	ETH (Ecoinvent)	ATHENA	DEAM (EU)	RMIT	LISA	LCAid
Items		2,500 (processes)	>20 (products)*	2,000 (processes)	>100 (products)	700 (modules)	> 30 (products)	>50 (items)	N/A
		5 (Good)	1 (Poor)	5 (Good)	3 (Medium)	3 (Medium)	1 (Poor)	3 (Medium)	3 (Medium)*
Regional Scope		Europe (included Australia)	Switzerland, Europe		North America	North America, Europe	Australia	Australia	Australia
		5 (Good)	1 (Poor)	1 (Poor)	1 (Poor)	1 (Poor)	5 (Good)	5 (Good)	5 (Good)
Time Boundary		96-99	88-90	96-99	92-99	91-98	N/A*	N/A*	N/A*
		5 (Good)	1 (Poor)	5 (Good)	5 (Good)	3 (Medium)	3 (Medium)	3 (Medium)	3 (Medium)
Environmental Emission/ Resources Consumption		250 items	300 items	770 items	N/A*	270 items	230 items	>10 items	>40 items
		3 (Medium)	3 (Medium)	5 (Good)	3 (Medium)	3 (Medium)	3 (Medium)	1 (Poor)	1 (Poor)
Cost		A$4,000	A$185	A$2,000	A$6,000-11,000	110 A$/module	Free	Free	N/A**
		1 (Poor)	5 (Good)	3 (Medium)	1 (Poor)	1 (Poor)	5 (Good)	5 (Good)	5 (Good)
Weighting Cases	Same importance	19	11	19	13	11	17	17	17
	Most important to Items	29	13	29	19	17	19	23	23
	Most important to regional boundary	29	13	21	15	13	27	27	27
	Most important to Time	29	13	29	23	17	23	23	23
	Most important to Cost	21	21	25	15	13	27	27	27

linguistic terms: Good (5), Medium (3), Poor (1),
*: linguistic value is assumed as “Medium”.
**: linguistic value is assumed as “Good”.

Discussion

Figure 3 shows the weighted ranking scores for the databases considered and Figure 4shows the ranking score for the databases which are normalized to the largest one for each database.

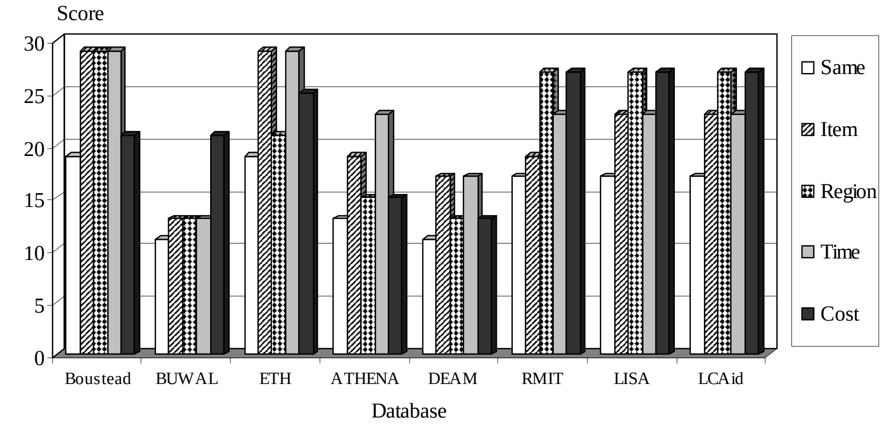

Figure 3 Comparison of selected databases

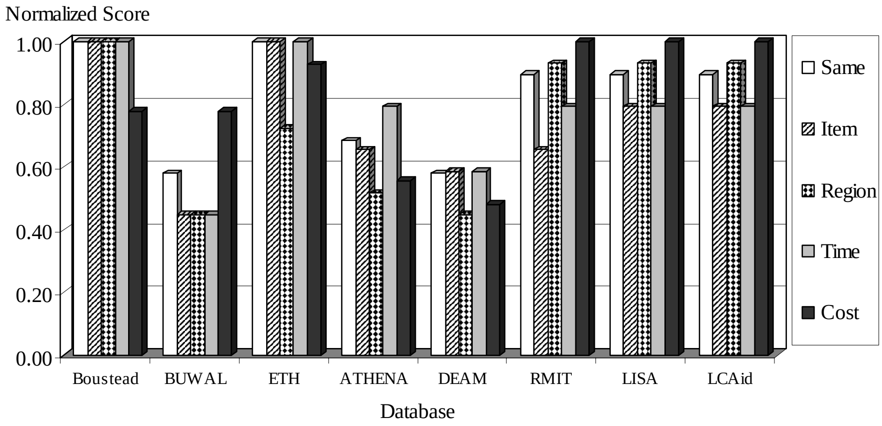

Figure 4 Comparison of selected databases with normalisation value (Best value = 1)

In Figure 3 or Figure 4, the higher the score, the better the database. From the comparison shown in Figure 3 and Figure 4, the Boustead database has the highest score in the four types of weighting (Same, Item, Region, Time) except for cost (ranked 3rd). Also, the ETH database has a high score in several weighting types such as "Same", "Item", "Time" and "Cost" except for "Region", which may be very important when considering databases for a particular region.

The other databases such as RMIT, LISA, and LCAid have high scores in the weighting type of "Region" and "Cost" as they focus on Australian data. They have a lower score, however, when "Items", or "Time" are considered more important factors.

Thus, it is recommended to choose the Boustead or ETH as an adequate database for the CRC CI project. However, the ETH database is not available presently and also does not cover Australia regionally. Thus, it is recommended the Boustead database is better to construct the environmental inventory analysis for the Australian commercial building assessment under the present situation.

Appendix F - Targets of HQE (High Environmental Quality)

Targets	Sub targets
Targets of eco-construction	
1. Harmonious relation of the buildings with their immediate environment	• Use of the opportunities offered by the vicinity and the setting • Management of the advantages and disadvantages of the parcel • Organization of the parcel in order to create a pleasant living environment
2. Selection of construction processes and building products	• Adaptability and durability of the buildings • Selection of construction processes • Selection of construction products
3. Building sites with low nuisance	• Management of construction waste issued from the building site • Reduction of noise pollution on the building site • Reduction of the pollution issued from the parcel and the vicinity • Control of other types of pollution issued from the building site
Targets of eco-management	
4. Energy management	• Favoring the decrease of the energy requests and needs • Favoring the use of environment-friendly energies • Increase of the efficiency of the energy equipment • Use of clean generators when using burning generators
5. Water management	• Management of drinking water • Use of not-drinking water • Insurance of wastes water cleaning • Assistance in rainwater management
6. Wastes management	• Design of waste deposits adapted to the current or future modes of waste collection • Waste management adapted to the current mode of waste collection • Maintenance
7. Maintenance	• Optimization of the needs for maintenance • Implementation of effective processes for technical management and maintenance • Control of the environmental impacts of maintenance processes
Targets of comfort	
8. Hygrothermic comfort	• Maintaining hygrothermic comfort conditions • Homogeneity of hygrothermic ambiance • Hygrothermic zoning
9. Acoustic comfort	• Acoustic correction • Acoustic insulation • Reducing noise due to impacts and to the equipment • Acoustic zoning
10. Visual comfort	• Pleasant visual relation with the outside environment • Optimum natural lighting with regard to comfort and energy expenses • Artificial lighting complementary to natural lighting
11. Olfactory comfort	• Reduction of bad smell sources • Ventilation intended for bad smell exhaust
Targets of heath	

Bruno Mesureur, 2002

AUTHOR BIOGRAPHY

Dr Seongwon Seo began his research into sustainable construction with a research project on life cycle cost assessment for reinforced concrete building at Chung Ang University, Seoul, Korea and on recycling and treatment for construction and demolition wastes in the City of Seoul in 1995. He then supervised and taught graduate students and researched environmental impact potential for urban environmental problems with a BK (Brain Korea) 21 Postdoctoral Research Fellowship at the Department of Environmental Engineering, Inha University, Inchon, and Korea Department of Urban Engineering, before taking up a fellowship at the University of Tokyo, Tokyo, Japan to undertake research in life cycle assessment and to develop the assessment methodology for environmental sustainable development for urban infrastructures in 2000. He continued his work on environmental sustainability for urban infrastructures using a fuzzy composite method as a foreign research fellow followed by a COE (Center of Excellence) Research Fellow, Research Center for Advanced Science & Technology (RCAST), at the University of Tokyo. He joined CSIRO Division of Manufacturing and Infrastructure Technology as a researcher on environmental assessment systems for commercial buildings in the Cooperative Research Centre for Construction Innovation in April, 2002.

His research interests focus on Environmental Management System, Life Cycle Assessment (LCA), Environmental System Analysis, Urban Environmental Problems, Built Environment, and Global Warming.

Recent publications

Seongwon Seo, Yongwoo Hwang, "Estimation of CO_2 Emissions in Life Cycle of Residential Buildings", *Jour. of Construction Engineering and Management, ASCE*, 127(5), 414-418, October 2001

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